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ABSTRACT

This report summarizes the findings and conclusions from the first phase of a study entitled "Assessment of Initiatives Available to Address Problems and Opportunities in K-12 Science Education." The study was done for the National Science Foundation (NSF) as part of its response to a congressional requirement that NSF seek outside assistance in developing a strategic plan for science and engineering education. The document contains a brief overview of all findings and conclusions regarding NSF's mission in K-12 science education. Problems are identified in K-12 science education that constrain the development of a broad pool of competent, interested science learners and opportunities are described which use the capabilities of NSF to address these problems. In addition, the report calls on NSF to maintain an adequate level of support for non-goal-directed core functions that underlie the success of NSF's efforts to address these opportunities. Finally, suggestions are made regarding ways for NSF to design initiatives to address particular opportunities within an overarching strategy. Two strategy options are described, each of which sets objectives related to the overall goals, and guides the choice of initiatives so that they are mutually reinforcing and consistent. The appendices include a delineation of these initiatives. (TW)

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OPPORTUNITIES FOR STRATEGIC INVESTMENT IN K-12 SCIENCE EDUCATION

Options for the National Science Foundation

Summary Report

May 1987

U.S. DEPARTMENT OF EDUCATION
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The results of this study are reported in three volumes:

The *Summary Report* (this volume) contains a brief overview of all findings and conclusions regarding NSF's mission in K-12 science education, the opportunities for the Foundation to make a significant contribution to solving problems in K-12 science education, and how NSF can approach these opportunities more strategically.

Volume 1 - Problems and Opportunities presents full discussions of NSF's mission, the problems in K-12 science education that are susceptible to NSF's influence, and the opportunities to address these problems. Essays on each opportunity present an analysis of:

- The rationale for NSF's involvement.
- How current (or projected) NSF programs and policies, carried out by its Directorate for Science and Engineering Education (SEE), relate to the opportunity.
- Promising alternative initiatives for SEE to take advantage of the opportunity.

Volume 2 - Groundwork for Strategic Investment contains extended discussions of:

- NSF's "core" or basic functions in science education (promoting professional interchange, building a base of information and knowledge about science education, and supporting innovation).
- The basis for strategic investment in K-12 science education (design of initiatives, development of strategies and strategic capacity).

This volume also includes a discussion of study methods, a summary of NSF's 30-year history of funding in K-12 science education, and three commissioned papers (regarding NSF's role in mathematics education, computer science education, and efforts to serve minority students in science).

The conclusions of this report are those of the authors and contractors and do not necessarily reflect the views of the National Science Foundation or any other agency of government.

HIGHLIGHTS OF THE REPORT

This report summarizes findings and conclusions from the first phase of SRI's "Assessment of Initiatives Available to Address Problems and Opportunities in K-12 Science Education." The study was done for the National Science Foundation as part of its response to a congressional requirement that the Foundation seek outside assistance in developing a strategic plan for science and engineering education.

NSF's Mission in K-12 Science Education*

Any assessment of NSF's options for improving K-12 science education rests on a conception of the Foundation's overall goal or mission in education. We derived a statement of mission by analyzing:

- Contrasting views of NSF's legislated mandate to "strengthen science education at all levels."
- The growing public and professional consensus on important goals for science learning.
- Demographic trends in the population of students.
- Patterns of student performance and motivation.

We concluded that:

> **At the K-12 level, NSF can best serve the scientific and engineering enterprise, and the society as a whole, by promoting the development of a broad pool of competent and interested science learners through the age of 18.**

Fulfilling the Mission

The Foundation's K-12 science education programs located in the Directorate for Science and Engineering Education (SEE) are making various contributions to the

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* Throughout this report, we use the terms "science education" and "education in the sciences" generically to include education in mathematics, the natural sciences, engineering, and technology (as both a tool and object of study), except where differences between the disciplinary areas are specifically indicated. Similarly, we use the term "K-12" to encompass all science learning activities for children and youth from 5 through 18 years of age, both inside and outside of school.

fulfillment of this mission. Where and how should NSF next invest its resources? How can it optimize its contribution toward accomplishing this goal? Our answer to these questions comes in three parts:

Identify targets of opportunity. We have identified the problems in K-12 science education that constrain the development of a broad pool of competent, interested science learners and that are susceptible to the Foundation's influence. In relationship to these problems, we have described opportunities for addressing them, in which NSF's unique capabilities can be brought to bear on relevant aspects of the problem in a timely way.

Support core functions. NSF must maintain an adequate level of support for non-goal-directed activities that underlie the success of its efforts to address opportunities. These "core functions" include: promoting professional interchange among members of the science education community, especially between educators and scientists, mathematicians, and engineers; developing a base of information and knowledge about science education; and supporting innovation on an open-ended basis.

Invest strategically. We have suggested ways for NSF to design initiatives to address particular opportunities within an overarching strategy. We describe two strategy options, each of which sets objectives related to the overall goal and guides the choice of initiatives so that they are mutually reinforcing and consistent. To do so means that NSF must build its "strategic capacity"--that is, its institutional capability, located in SEE, to carry out these investments over the long term.

We summarize our conclusions about each topic as follows.

Identifying Targets of Opportunity

Aside from deep social forces that NSF is not in a position to ameliorate, the fundamental problem--a limited pool of competent and interested science learners--can be traced to three interrelated sources:

- What is taught and how it is taught.
- The supply and quality of teachers and support of the surrounding professional community.
- The functioning of educational systems that bear on the teaching and learning of science and mathematics.

These are amenable to attack through NSF's grant programs and other activities. The Foundation's central position, substantial discretionary resources, and connection with the diverse groups concerned with science education, among other factors,

enable it to play a significant leadership role. Opportunities exist for NSF to bring these strengths to bear on critical needs in the three problem areas.

We have identified three sets of opportunities:

- **The time is ripe for NSF to guide the search for more appropriate content (broadly defined to include knowledge, skills, and attitudes) and approaches to education in the sciences.** Separate opportunities exist for doing so in relation to K-12 mathematics, elementary science, and science at the middle and high school levels. In addition, the opportunity exists to explore ways to match science and mathematics curricula to diversity in the student population.

- **Opportunities exist for NSF to strengthen the elementary and secondary teaching force and the broader community of professionals concerned with educating young people in the sciences.** In particular, NSF is well positioned to develop an extensive leadership group providing support to current (and newly entering) teachers, restructure approaches for preparing the next generation of teachers, and support professional development among informal science educators.

- **Certain institutions in the "infrastructure" for formal and informal science education provide the Foundation with key leverage points in the functioning of current educational systems.** Opportunities exist to address science and mathematics testing, the publication of improved materials, the support of state reform efforts, and the expansion of informal science learning resources.

SEE's K-12 programs have evolved rapidly since the Directorate's reestablishment in late 1983, and are increasingly targeting efforts toward these kinds of opportunities. Recent special-purpose solicitations within these programs show particular promise of addressing several opportunities. However, as currently operated, SEE's K-12 programs are unlikely to take full advantage of the opportunities for several reasons, among them the diffuse nature of some programs' goals, the lack of priority given to certain opportunities (e.g., science testing, state education reform), and the current level of SEE's resources (which is insufficient to address all the opportunities, even if SEE wanted to). Adjustments in program priorities and implementation (see below) will enable SEE to take better advantage of these resources.

Supporting Core Functions in Science Education

Underlying any efforts to pursue these opportunities are investments of a different kind that support the efforts of the science education community in a less goal-directed way. Support of this kind fulfills three "core functions" in science education, for which NSF is especially well qualified:

- *Fostering ongoing professional interchange,* especially between educators and members of the scientific community.

- *Developing a cumulative base of information and knowledge* about science learning and learning environments, the science education system as a whole, and the results of (NSF's) interventions in that system.

- *Encouraging innovation* (without reference to a particular goal or program priority).

These things happen--to a limited extent--as part of goal-directed investments, but they need to be nurtured more extensively, and on an ongoing basis, if an adequate "intellectual infrastructure" is to be maintained, both to provide NSF with a basis for planning further investments and as a way of preparing the professional community (from which proposals come in response to any targeted efforts).

SEE now supports some core functions more effectively than others. All of these functions deserve to be established on a secure basis, and therefore should figure prominently in SEE's planning for the future.

Investing Strategically

By comparison with the Foundation's predominant mode of field-guided support for scientific and engineering research, NSF must be proactive and strategic in supporting improvement in K-12 science education. The complexity of the educational system and the relationship of NSF to the system demand that the Foundation place its investments with care and actively promote needed changes in the system.

To guide the investment of funds and staff time, NSF must be strategic at two levels. At the program level, initiatives must be designed to take advantage of promising opportunities to reach objectives related to the long-term goal. At the level of the Directorate and NSF as a whole, an overarching strategy must be adopted to help determine priorities and explain how SEE will meet the goal of developing a broad pool of competent, interested science learners.

For those opportunities that NSF (SEE) chooses to address, it needs to design and implement initiatives that maximize the impact of the Foundation's dollars. In the past few years, SEE has shown an increasing ability to mount effective initiatives, which draw on NSF's strengths, are oriented toward specific targets (some corresponding to the opportunities we have described), and take advantage of timely events or potential collaborators in the professional community. Guided by a similar set of criteria, we have developed initiatives related to each opportunity, which SEE should consider in its planning for the future (see Appendix A for a listing of these initiatives).

The chances of achieving the goal of developing a broader pool of competent and interested young science learners are further increased if NSF develops an overarching strategy to guide the choice of opportunities and initiatives so that they are mutually supportive and consistent. Such a strategy would: (1) be oriented toward the overall goal of broadening the learner pool; (2) include a mutually supportive set of initiatives aimed at improving content and approach, professional resources, and the functioning of educational systems; and (3) exhibit a clear philosophy of educational change and NSF's relationship to it.

Currently, one can discern two contrasting strategies at work within and across SEE programs:

- *Incremental improvement strategy.* This strategy emphasizes upgrading current formal and informal educational systems, primarily through investments that achieve widespread and incremental impacts in the short term. Support for collaborative ventures with publishers to improve course materials, inservice teacher education, or national children's science and mathematics broadcasts are examples of efforts that reflect this strategic approach to improving education.

- *Fundamental change strategy.* This strategy aims at exploring the possibilities, extending the state of the art, and searching for "breakthroughs" and new approaches that can radically improve education over the long term. Research efforts focusing on understanding the processes of science learning, exploration of technological innovations, and long-term leadership development programs illustrate the nature of investments compatible with this strategy.

Each of these two strategies has historically been promoted by different constituencies as the most suitable basis for the Foundation's educational investments, and an unstated tension between the two continues at present. Neither has been clearly articulated above the level of individual programs, and even within programs the predominant strategy has not always been clarified. Each of the two strategies presents a fundamentally different philosophy of educational change and implies a different role for NSF to play in the change process.

It is possible--and, we would argue, beneficial--for NSF to adopt one or the other (or a suitable alternative) as the primary direction for SEE's K-12 educational investments. Along with a clear statement of mission (broadening the pool), a publicly declared Directorate-wide strategy for carrying out that mission would have considerable internal as well as external benefits. Such clarity would greatly assist outside agencies and members of the professional community in understanding "what business" NSF was in. It would help to explain and justify current and projected budget allocations for the full range of SEE's investments. It would also help provide guidance about the priorities for future investments, as well as a basis for adjusting current programs where their strategic emphases are unclear. Finally, it would empower SEE staff by providing a clearer sense of purpose in their work.

We have not found evidence that either of these strategies is clearly superior to the other. Rather, they represent trade-offs, which must be weighed carefully.

- Investing primarily in incremental improvement is eminently practical, has greater promise for reaching students soon, and appeals to key political constituencies. In many respects, this strategy is an easier choice, because it represents a direction that is beginning to emerge in SEE's more recent investments and plans for the future. However, it is ultimately more costly, is less appealing to the scientific community, and may result in improvements that are insufficient to meet the ultimate goal.

- Investing in fundamental change, on the other hand, will generate more intellectual excitement within the academic science education (and scientific) community and is more likely to lead to breakthroughs in conceptions of curricular content and educational approach. But the strategy offers less guarantee that these powerful ideas will make their way into practice; consequently, it may be less appealing to practicing educators and political constituencies.

The basic challenge to the Foundation is to take one or the other direction (or a suitable alternative) as the primary emphasis for its K-12 science education investments, while maintaining a balanced portfolio of investments of various kinds. The choice of an overarching strategy need not preclude other types of investments--a mixture of investments will always be needed to address existing opportunities effectively. **The best strategy will be one that SEE leaders are most comfortable pursuing and can convince other NSF leaders to support and articulate inside and outside the Foundation.**

Becoming more strategic and proactive requires a "strategic capacity" within the Foundation: staff, resources, procedures, and support. **Within its Education Directorate, NSF has already developed considerable capacity for investing strategically in K-12 science education. SEE needs to develop its capacity further, with the full support of the Foundation as a whole.**

Further improvement in NSF's strategic capacity for K-12 science education means that SEE and NSF leadership will:

(1) Maintain a centralized home base within the Foundation for K-12 science education (in SEE).

(2) Build the right staff expertise (e.g., by attracting a larger cadre of good permanent staff with grantmaking expertise, as well as rotating staff with expertise more closely matched to the opportunities to be addressed).

(3) Take steps to guarantee resources corresponding to strategic plans for K-12 science education.

(4) Review procedures and policies that enable SEE staff to be proactive (e.g., expectations for the use of staff time within SEE, staff FTE ceilings for the Directorate).

(5) Increase support from the Foundation's top leadership for K-12 science education (e.g., by having NSF leaders and the National Science Board assist with the public articulation of the Foundation's K-12 science education strategy).

Finally, NSF as a whole must recognize the fundamental differences between support for the scientific research enterprise and support for the enterprise of science education, in which NSF's role combines research with efforts to stimulate change in educational systems. But whatever the differences, the two enterprises ultimately serve ends that are closely related; consequently, they deserve the same quality of commitment from the Foundation.

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INTRODUCTION

After a period of noninvolvement during the early 1980s, the National Science Foundation (NSF) has once again become active with regard to education in the sciences* at the precollege and other levels, in concert with the nationwide movement to improve education in mathematics, science, and technology. Following the reinstatement of NSF's Directorate for Science and Engineering Education (SEE) in late 1983, the Foundation has rebuilt its K-12 program structure and launched new initiatives aimed at this level. The rebuilding process has raised old questions and new possibilities about the most appropriate and effective directions for NSF's future investments in this area.

During the course of the rebuilding process, Congress required NSF to seek outside assistance in developing a "science education plan and management structure in the Foundation." As part of NSF's response to that requirement, SEE awarded SRI International a contract in 1986 to perform "An Assessment of Initiatives Available to NSF to Address Problems and Opportunities in Science Education." This document summarizes the results of that project's first phase.**

The Study

In conducting the study, we looked broadly at the range of opportunities available to NSF for improving K-12 science education. We searched for particularly promising and timely opportunities aimed at critical national needs in science education and appropriate to NSF as a federal science grantmaking agency. Having identified promising opportunities, we then assessed the extent to which current (and projected) NSF programs and priorities, along with promising alternatives, will take advantage of these opportunities. In doing so, we simultaneously examined NSF's overall goals and strategies in science education and identified important options facing the Foundation at this level.

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* Throughout this report, we use the terms "science education" and "education in the sciences" generically to include education in mathematics, the natural sciences, engineering, and technology (as both a tool and object of study), except where differences between the disciplinary areas are specifically indicated. Similarly, we use the term "K-12" to encompass all science learning activities for children and youth from 5 through 18 years of age, both in school and outside of school.

** During the second phase of the project, SRI will develop and pilot test procedures for SEE's ongoing assessment of its programmatic activities.

Our findings draw on a wide range of information sources: (1) the deliberations of prominent experts in five working groups (on school-based science education, school-based mathematics education, technology in science and mathematics education, the development and support of science and mathematics teachers, and informal science education); (2) historical review of NSF's precollege programs from 1952 to the present; (3) interviews with more than 600 science educators, project directors, current or former NSF staff, members of the scientific community, staff in private foundations, and other observers; (4) reviews of the literature and NSF documents (program announcements, evaluations, annual reports, etc.); (5) an analysis of SEE's project funding patterns over the past 3 years; and (6) the reactions of numerous reviewers to draft reports, including professional society and association representatives, science and mathematics education faculty, working scientists and mathematicians, and others.*

NSF's Mission in K-12 Science Education

Any assessment of NSF's investment possibilities rests on a conception of its legislated mandate "to strengthen science education at all levels," and in particular on its overall goal or mission in K-12 science education. We base our assessment on the following proposition:

> **At the K-12 level, NSF can best serve the scientific and engineering enterprise, and the society as a whole, by promoting the development of a broad pool of competent and interested science learners through the age of 18.**

We derive this proposition from four sources: (1) an analysis of contrasting views of education for scientific and engineering occupations--often referred to as the "pipeline," (2) a growing national consensus about significant goals for education in the sciences, (3) disturbing patterns of motivation and performance among K-12 science learners, and (4) the fact that the numbers of students--and therefore science learners--in middle and high school grades will decline over the next decade.**

Our analyses assume that the Foundation's interpretation of its mandate to strengthen science education must always include the preparation of personnel for the scientific/technical pipeline. To accomplish this goal, NSF may base its support for K-12 science education on two contrasting views of preparation for scientific and engineering occupations: (1) "skimming the cream," i.e., early identification and enhanced education for the most talented students, or (2) "broadening the pool," i.e., supporting enhanced education in the sciences for all young people to increase

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* For a full discussion of these issues and the documentation for our conclusions, the reader is referred to *Volume 1 - Problems and Opportunities*.

** Study methods are described more fully in *Volume 2 - Groundwork for Strategic Investment*.

the number of students who are competent and interested in mathematics and the sciences.

Whereas at higher levels of education a narrowly focused view of pipeline development may make sense, there are grounds for believing that, at the K-12 level, efforts to broaden the pool will contribute more to the nation's occupational needs than skimming the cream. First, and most important, it is difficult and often impossible to tell which students at the elementary and secondary school levels will remain in the pipeline, as Figure S-1 schematically suggests. Second, the decreasing size of the student population at the middle and high school levels over the next 10 years and the rate at which students lose interest in (and drop out of) science-related courses will reduce the pool from which all technically based occupations, not just research science and engineering, draw personnel.

Investments in broadening the pool are especially important in light of other important learning goals. Broad national consensus has developed over the past half dozen years that the most pressing needs in K-12 science education lie in the nation's failure to educate the majority of young people to an adequate level of science literacy. Science education, it is argued, should ensure both the public's understanding of science and its ability to cope with the demands that a scientific and technologically dominated society places on individuals. Either on the narrower grounds that the Foundation must do so to ensure adequate public support for science and engineering or on the broader basis that national scientific literacy is properly its domain, NSF has reason to devote its energies to broadening the pool of science learners up to age 18. Preoccupation with the development of future scientists and engineers as an exclusive K-12 educational mission makes little contribution to non-occupational science learning goals or to public appreciation of the scientific and engineering enterprise.

The need for concentrating on a broader pool of students, and on their levels of competence and interest, is strengthened by patterns of student motivation, performance, and demographic change. In terms of overall national averages, students nationwide do not compare favorably with their counterparts in comparable industrialized nations. American students are not gaining sufficient higher-order thinking or problem-solving skills. Even among the more able students, who perform well in many respects, there are grounds for concern: advanced courses are not as challenging as they might be; students in other nations outperform them in both science and mathematics. Student performance reflects low motivation for science and mathematics learning among the majority of students at middle and high school levels, and correspondingly modest expectations on the part of parents.

The declining size and changing composition of the middle and high school age cohort accentuate current patterns in the science learner pool. Over the next decade, for example, an increasing proportion of the total student population will be of racial and ethnic minority background. Patterns of participation and achievement are generally lower for most minorities, as well as other groups underrepresented in the sciences (such as women or the physically handicapped). Getting more students from underrepresented groups into the pipeline, it is widely agreed, means

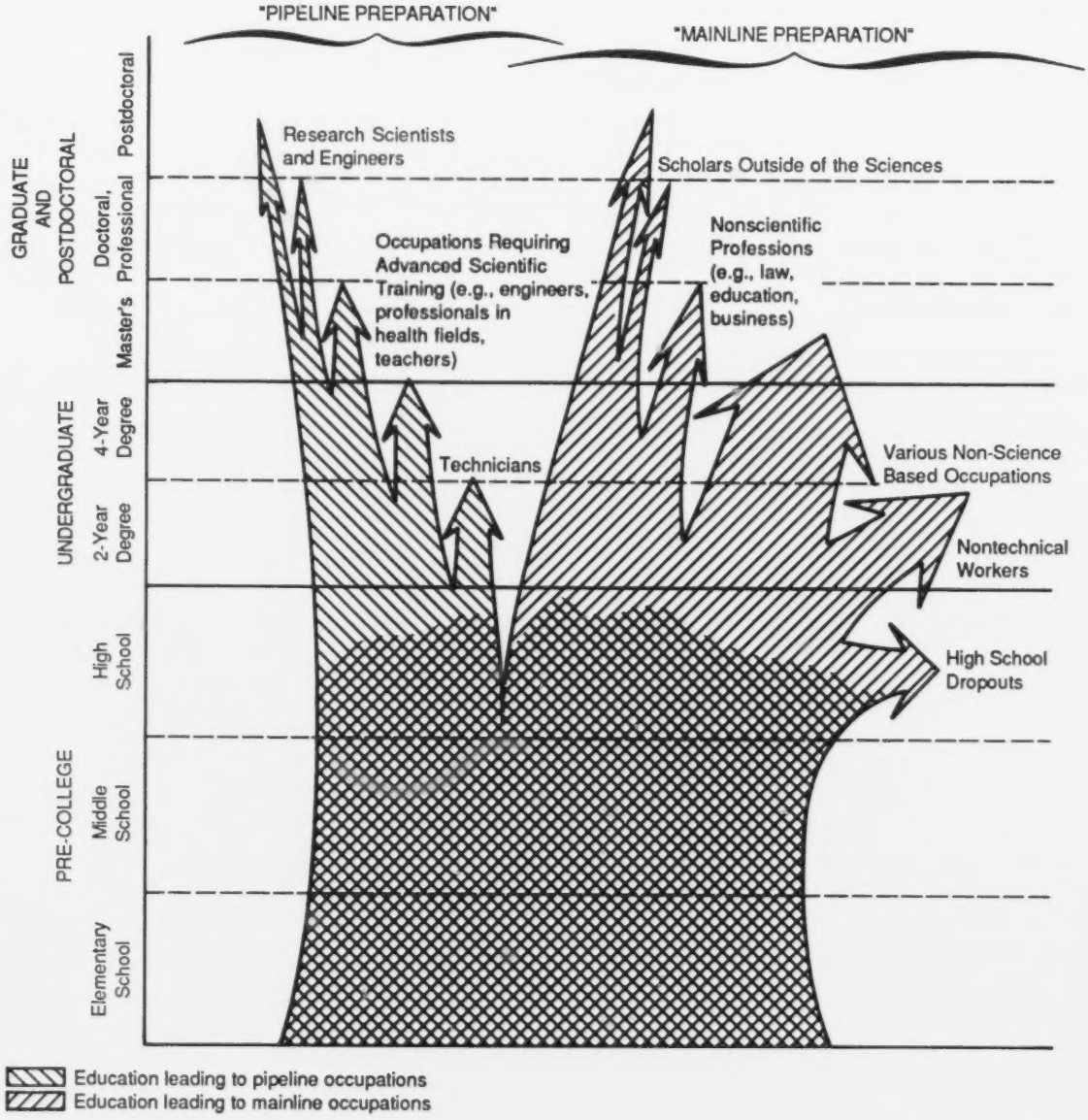

FIGURE S-1 EDUCATION IN THE SCIENCES ACROSS EDUCATIONAL LEVELS, FOR DIFFERENT OCCUPATION PREPARATION STREAMS

intervening early in the schooling process to increase interest, achievement, and participation.

These arguments support the premise that NSF's primary mission at the K-12 level is to promote interest, knowledge, and intellectual skills in science and mathematics for a broad range of learners. To do so implies a vision of science education for children and youth that features: a general core of mathematics, science, and technology-related content and instruction for everyone throughout school; a set of supplementary, school-based experiences for brighter and more motivated students; and a complementary array of learning opportunities available, outside of school, to students of all age levels and abilities. This vision comprises, in general terms, an appropriate strategic goal for NSF activities at the K-12 level over the next 10 years.

Fulfilling the Mission

The Foundation's K-12 science education programs located in the Directorate for Science and Engineering Education (SEE) are making various contributions to the fulfillment of this mission. Where and how should NSF next invest its resources? How can it optimize its contribution toward accomplishing this goal? Our answer to these questions comes in three parts:

Identify targets of opportunity. We have identified the problems in K-12 science education that constrain the development of a broad pool of competent, interested science learners and that are susceptible to the Foundation's influence. In relationship to these problems, we have described opportunities for addressing them, in which NSF's unique capabilities can be brought to bear on relevant aspects of the problem in a timely way.

Support core functions. NSF must maintain an adequate level of support for non-goal-directed activities that underlie the success of its efforts to address opportunities. These "core functions" include: promoting professional interchange among members of the science education community, especially between educators and scientists, mathematicians, and engineers; developing a base of information and knowledge about science education; and supporting innovation on an open-ended basis.

Invest strategically. We have suggested ways to design initiatives to address particular opportunities within an overarching strategy. We describe two strategy options, each of which sets objectives related to the overall goal and guides the choice of initiatives so that they are mutually reinforcing and consistent. To do so means that NSF must build its "strategic capacity"--that is, its institutional capability, located in SEE, to carry out these investments over the long term.

We summarize our conclusions about each of these topics in the three sections that follow.

PROBLEMS AND OPPORTUNITIES

Numerous analyses and national commission reports, together with our own investigation, help to identify problems in K-12 science education that keep the pool of science learners small and underprepared.* A synthesis of these analyses reveals the complex, systemic character of these problems and the solutions to them. In light of NSF's mission and capabilities, we have identified possible points of intervention and promising opportunities for the Foundation.

Problems in K-12 Science Education That Limit the Pool of Science Learners

The long-term goal of broadening the pool is more likely to be reached if a significant effort is devoted (by NSF and others) to three interrelated aspects of K-12 science education: (1) the content of, and approach to, instruction; (2) the strength of the professional community, especially the teacher force; and (3) the influence of the educational system as a whole on the classroom or setting for learning.

The current state of the science learner pool can be traced to three interrelated aspects of formal and informal educational settings and also, more indirectly, to deeper cultural and social forces. Whereas these deeper forces lie somewhat beyond the reach of NSF's education initiatives, the more immediate causes within educational systems present potential targets for NSF's intervention.

Content and approach--The content of science and mathematics instruction in school is often inappropriate with regard to students' interests and cognitive development at different ages, contemporary ideas in mathematics and the scientific disciplines, and the kinds of knowledge and intellectual skills needed in a modern society. Science curricula tend to emphasize encyclopedic coverage of material; mathematics curricula emphasize the repetitive coverage of computational skills and arbitrary assignment of "advanced" topics (algebra, geometry, calculus) to particular grades. Curriculum and instruction in both science and mathematics suffer from an inadequate experiential base, including the limited use of technologies such as the calculator and computer.

These patterns suggest the need for fundamentally restructuring what is learned and how it is taught. This means grappling with deep issues of scientific and mathematical "content"--broadly construed to include knowledge, skills, and attitudes

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* For a full discussion of these problems and associated opportunities, along with the documentation on which we based our conclusions, the reader is referred to *Volume 1 - Problems and Opportunities*.

conveyed by instructional materials and by instruction itself. New conceptions of K-12 science and mathematics content (and related instructional approaches) are needed that:

- Identify unifying principles across the sciences and consider alternatives to current disciplinary organization (biology, chemistry, algebra, calculus, etc., as separate subjects).
- Integrate technology into science and mathematics courses, both as a tool and as a subject of study (e.g., computer science, pre-engineering).
- Investigate the applications of science and technology and their impact on society and economics.
- Provide in-depth science and mathematics learning opportunities to balance the emphasis on breadth of coverage in most current curricula.
- Reassess experiential learning and ways to achieve it.
- Fit instruction and environments for learning to students at different ages or developmental levels.

The strength of the professional community--Restructuring the content of science and mathematics education will work only if there are teachers capable of teaching it. One of the weakest links in the current system, the science and mathematics teacher force is currently underqualified and promises to be more so in the coming decade. The deficiencies in the teaching force can be traced to a number of factors, many of which are not susceptible to NSF's influence--such as the economics of the professional labor market, the relatively low status of teaching (at both school and university levels), and the pervasive misassignment of teachers in school districts undergoing enrollment decline. Other aspects of the problem--for example, the nature of professional training, the system of professional rewards and incentives, and the vitality of the professional community--present the Foundation with problems it can address.

The quality of the teaching force is related to the strength of the larger community of professionals who are concerned with education in the sciences: developers, teacher educators, members of the scientific community, informal science educators, educational researchers, and others, as well as elementary and secondary school teachers. Collectively, these groups comprise a "community" in only the loosest sense; the profound cleavages between educators and scientists, educational researchers and practitioners, etc., are well known. But there are signs that this community is ready for revitalization, among them: national reform movements are pushing toward the professionalization of teaching, and the scientific community has become more sensitized to the need for science education reform. NSF's history amply demonstrates that the Foundation can make a major contribution to professional development, leadership, and intellectual discourse within this community; for example,

NSF summer institute participants of the 1960s are among today's leaders in science education.

The way educational systems constrain or reinforce science learning--Improved content and a stronger professional community will not by themselves change what happens in science and mathematics classrooms (and outside of schools). Many organizational elements inside and outside the school district interact to constrain or reinforce science learning. Locally, school and district curriculum policies, resource allocation, inservice training programs, and administrative support have a great deal to do with the quality of instruction. State policies regarding testing, graduation requirements, or textbook adoption set boundaries around what the schools are willing to teach. Publishers, in effect, set limits on curriculum by what they put in course materials; the materials, in turn, reflect market demand, especially as expressed in policies of key textbook-adoption states.

Because NSF cannot intervene directly or comprehensively within this system, it must identify points of leverage where its influence is legitimate, significant, and cost-effective. The Foundation can work through institutions in the educational infrastructure that most directly influence the quality of educational content or teaching within schools. It can expand science learning opportunities outside of schools, and it can promote demonstrations in sites where all the components of good science education are effectively integrated.

Six characteristics of the Foundation and its Education Directorate distinguish it from other actors, enable it to address the kinds of problems we have identified, and at the same time define the roles it can and cannot play:

(1) *National purview*, which permits NSF to identify and address concerns confronting schools nationwide, but at the same time limits its role in improving science education for a particular state or locality (except as a model for others).

(2) *Independence as a federal foundation*, which gives NSF flexibility to mobilize others but, unlike the U.S. Department of Education, no regulatory authority and, like all federal agencies, constitutional limitations on its role in education at the state and local levels.

(3) *Connection to the mathematics, science, and engineering communities*, which makes NSF the logical agency to facilitate translating scientific disciplines into educational terms, yet at the same time limits its familiarity with the educational establishment.

(4) *Large amounts of discretionary funding* relative to others in science education, although small relative to the scale of the educational enterprise and the problems besetting it.

(5) *A central position* in relation to actors interested in improving science education.

(6) *An established track record in K-12 science education*, especially at the secondary school level, including a reputation for supporting only high-quality projects and providing long-term support where appropriate.

Opportunities for NSF

NSF has opportunities to guide the search for appropriate content and approach, improve professional capacities, and influence key institutions in the education infrastructure.

We have identified 10 current opportunities for NSF to address the problems that limit the pool of science learners. These opportunities are summarized in the following pages and are listed in Table S-2 at the end of the section. In each case, the Foundation has unique capabilities to address the problem and, at the same time, trends or the positioning of other actors make it timely for NSF to play a role, as displayed schematically in Figure S-2. Various conditions make the situation opportune for NSF. For example, a critical mass of potential contributors to change exists, but they lack the stimulus or resources to coalesce and move forward; or new knowledge or technology has recently become available but is unlikely to be applied effectively without focused support. In 5 years' time these conditions may change, and a different set of opportunities will become apparent.

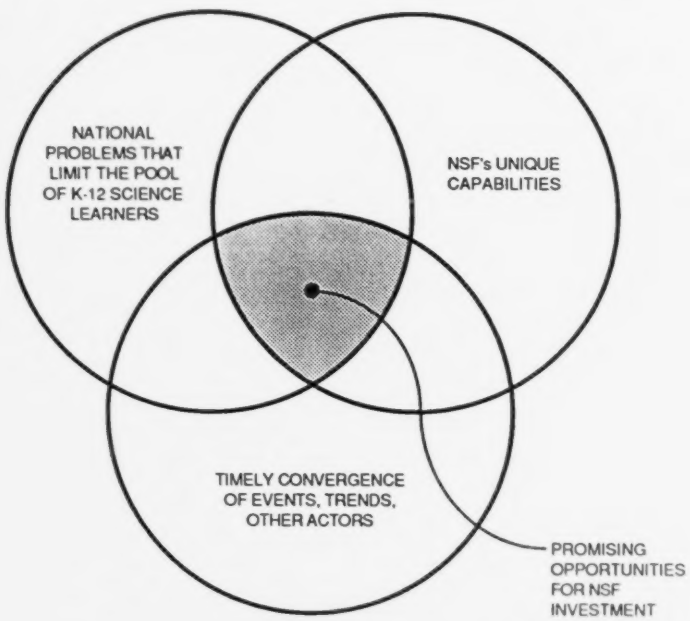
NATIONAL PROBLEMS THAT LIMIT THE POOL OF K-12 SCIENCE LEARNERS
NSF's UNIQUE CAPABILITIES
TIMELY CONVERGENCE OF EVENTS, TRENDS, OTHER ACTORS
PROMISING OPPORTUNITIES FOR NSF INVESTMENT

FIGURE S-2 IDENTIFYING OPPORTUNITIES FOR NSF

We summarize the opportunities briefly, grouped by the three aspects of science education that NSF is best equipped to address. (More detailed discussions of these opportunities appear in Volume 1 of this report.)

Appropriate Content and Approach

The time is ripe for NSF to orchestrate a thorough rethinking of what children and youth learn in science education and how it is taught. One opportunity presents itself for accomplishing this in mathematics:

- *Opportunity 1: To reconceptualize K-12 mathematics curricula and associated instructional approaches.* Starting in the earliest grades, mathematics education acts as a critical filter for students who might develop their interests and scientific skills. To broaden the pool, K-12 mathematics curricula (and instruction) need to be reconceived to reduce the repetitive focus on computation, to broaden the attention to other skills and topics (mathematical problem solving, probability and statistics, computer science, etc.), and to explore more thoroughly the various applications of mathematics. NSF (SEE) has made a good start at supporting efforts by the mathematics education community to reconceptualize mathematics (e.g., in relation to the computer and the calculator at the elementary level). Further investment is necessary, however, if this kind of thinking is to be extended to all grade levels and translated into workable curricular prototypes. The Foundation should consider comprehensive curriculum development, further support for efforts to set standards for the mathematics education community, and development of new software for mathematics instruction.

A parallel opportunity exists for the natural sciences (because of the less sequential nature of this subject area and substantial differences between educational levels, we present the opportunity in two parts):

- *Opportunity 2a: To rethink the approach to, and settings for, elementary science education.* This level of education is especially critical, given the mission of broadening the pool of competent and interested science learners and the fact that the population of students in the elementary schools is beginning to grow once again. These students' exposure to science has remained limited, despite NSF's earlier attempts to develop effective "hands-on" curricula. The massive systemic barriers to effective science instruction at this level call for further experimentation, with new approaches that build on what has been learned from "hands-on" science education and, at the same time, question the fundamental assumptions of these and other approaches. NSF (SEE) has recognized the need by making the elementary level a funding priority and is currently supporting work that explores several aspects of the problem. However, these projects are unlikely to achieve the bold rethinking that seems called for. The Foundation can expand its investments through appropriate research and large-scale field experiments on particular types of promising solutions (technology-based solutions, specialist systems, curricular integration, etc.).

- *Opportunity 2b: To reconceptualize the content of middle and high school science education.* In line with the overall goal of broadening the pool, the science education reform movement of the past half dozen years sets the stage for a thorough reconstruing of the content (knowledge, skills, attitudes toward science) of the science curricula taught to middle and high school students. Specifically, reform manifestos have called for greater effectiveness in teaching science to the majority of students, but this goal has yet to be translated into guiding conceptions (e.g., frameworks, course sequences). NSF's (SEE's) current and projected investments related to this opportunity concentrate on pieces of the problem: modules, new technological applications, experiments with "science, technology, and society" courses, etc. Investments aimed at the problem as a whole are needed to promote powerful new visions of learning in the natural sciences across these levels of education. NSF (SEE) should consider supporting high-profile national task forces to generate alternative curricular conceptions and initiate a process of developing professional consensus. At the same time NSF should support "bottom-up" experimentation with curricular prototypes by individuals and groups in the professional community.

A third opportunity reflects the fact that science and mathematics education must work for an increasingly diverse student population--in particular, for female and minority learners, who have not been well served by most past and present programs in these subject areas:

- *Opportunity 3: To match science and mathematics education to diversity in the student population.* Demographic changes in the student population, among other things, underscore the importance of renewing the quest for more satisfactory K-12 science and mathematics experiences for underrepresented groups, especially female and minority students. NSF's (SEE's) policy of the past 4 years--encouraging all proposals to consider the needs of these groups--has proved ineffectual so far: only a few projects address these needs. The answer is probably not a wholesale return to targeted, equity-oriented programs as in the 1970s; nonetheless, SEE should consider a variety of approaches, including student support programs, research on particular groups of students in relation to science learning, curriculum development targeted for the non-college-bound, and aggressive promotion of currently operating exemplary models.

The Strength of the Professional Community

Opportunities exist for NSF to strengthen the elementary and secondary teaching force and the broader community of professionals concerned with education in the sciences. Three opportunities are particularly germane, the first two concerning the current and future teacher force:

- *Opportunity 4: To bolster the support cadre serving mathematics and science teachers.* The large proportion of underqualified science and mathematics

teachers presents a critical challenge to NSF (and others) that must be met if the pool of science learners is to be significantly broadened. At the middle and high school levels, the opportunity for the Foundation lies in developing a nationwide "support cadre" consisting of "lead" teachers, local curriculum specialists, and others, who, in turn, act as a resource to middle and high school teachers on an ongoing basis. At the elementary level, NSF is in a position to stimulate the development of change advocates and leaders at the district and state levels. NSF's (SEE's) investments of the last few years in training "leadership teachers" provide some models for how this can be done, but the current scale and direction of NSF's inservice teacher support (which emphasizes innovative model development and workshops for the full range of teachers) is unlikely to contribute significantly to the larger goal. The Foundation should consider multiyear training for support cadre members through summer institutes and follow-up, expanded recognition programs, and supportive alliances between universities and school districts.

- *Opportunity 5: To help attract and prepare the next generation of well-qualified teachers.* To cope with the demands of teaching science and mathematics to a broadened pool of learners, the next generation of science and mathematics teachers must be imbued with a new sense of purpose, intellectual frameworks that are appropriate to the task, and the professional skills to accomplish the task once in the classroom. Substantial retirements over the next decade and a vigorous nationwide push toward teacher education reform make it opportune for NSF to invest in this area. Although many of the forces affecting the supply and preparation of science and mathematics teachers are beyond NSF's control, the Foundation has a significant contribution to make to the "professionalization" of science and mathematics teaching, the quality of teacher education experiences (in particular, the scientific content of disciplinary courses and subject-specific pedagogy), and the systematic documentation of current experiments with teacher education and recruitment approaches. SEE's current investments in this area focus on creating model programs for middle school teachers. Further investments on a broader range of targets--including increased support for teacher educators, efforts to increase understanding of teachers' pedagogical knowledge in science and mathematics, and experimentation with retraining approaches--would lead to more powerful impacts on the preparation of teachers.

- *Opportunity 6: To strengthen the informal science education community.* Over the last decade, educators outside of schools have assumed an increasing presence in K-12 science education--in particular through television, but also through institutions such as museums and science centers. These ways of conveying science education have an apparent capacity to motivate a wide range of learners and potential (though poorly understood) effects on the acquisition of knowledge, skills, and attitudes. This type of education is more likely to help broaden the pool of interested science learners given the right professional leadership, understanding of scientific and educational issues, and efforts to examine the potentials and limitations of informal media or approaches. In part a by-product of NSF (SEE) investment, a

critical mass of well-qualified, thoughtful science educators has begun to assemble over the last decade within the different media (television, radio) and institutions (museums, science centers). NSF has a long-term opportunity to expand the science education capabilities of these institutions and media by investing in further professional development, by supporting networks and collaboration (both within and across media), and by supporting research and evaluation efforts that can inform further efforts.

Institutions in the Educational Infrastructure

There are key leverage points in the "infrastructure" for science education. Although NSF is not a part of the educational establishment, it can be particularly influential with institutions that, collectively, exert great influence over curriculum and instruction in science classrooms. Three opportunities arise in this regard:

- *Opportunity 7: To improve and expand mathematics and science education publishing capabilities.* The quality and diversity of published science and mathematics materials are a major determinant of what is taught in science and mathematics classrooms. Although currently available materials are not particularly appropriate to the goal of broadening the pool, the increase in the student population and the interest in expanded science offerings signal a possible turnaround in the market for school and tradebook publications in science and mathematics aimed at school-age people. This situation presents NSF with a significant opportunity for near-term influence on the incentives and capacities of the publishing industry and the market to which it responds. Although the predominant mode of materials development over the last few years has been to leave questions of publication up to the grantees, SEE has started to support collaborative ventures with publishers in elementary science, which represents a potentially more effective way of engaging publishers in improving what they offer. NSF can also contribute to an expansion of the nation's science and mathematics education publishing capability over the long term by promoting alternative publishing routes for innovative materials that are unlikely to be supported by the established publishing houses.

- *Opportunity 8: To improve science and mathematics testing and assessment.* Testing influences curriculum and instruction in equally powerful ways; there is a growing belief (and some evidence) that current tests greatly constrain what teachers are willing to teach. The recent increase in school science and mathematics testing lends urgency to efforts to develop tests that capture the full range of skills, concepts, and attitudes that good science and mathematics teaching and restructured curricula convey (e.g., higher-order thinking skills; science laboratory skills). To date, SEE has done little to support work in this area, other than its contributions to national assessments. NSF's capacity for supporting cutting-edge R&D makes it an appropriate leader in the effort to create sophisticated and sensitive testing and assessment tools, as well as to understand the effects of current testing

policies and instruments. NSF can also increase the attention and work devoted to this issue, building on other efforts (e.g., the Mathematical Sciences Education Board) to examine these matters.

- *Opportunity 9: To provide content-related professional leadership in state science and mathematics education reform.* Although their direct influence on local practices varies, states are increasingly active in education reform, especially in science and mathematics. Reform policies such as increased graduation requirements have particular bearing on efforts to broaden the pool of science learners. The momentum of state-initiated reforms in science education and the relatively short window for sustaining a reform thrust (perhaps 5 years), combined with a vacuum in professional leadership in many states, provide NSF with important and immediate chances to help direct and translate reform energies into educational change. Since the National Science Board issued its report *Educating Americans for the 21st Century*, NSF (SEE) has done little to assist state-level groups with the practical task of carrying forward specific reforms; a few grants have been made to aid network development among state science education specialists and to help track progress of science education reforms. NSF has various options before it to take advantage of this opportunity, including promoting national dialogue on state science education reform policy, supporting technical assistance to state-level policymakers and science education planners, and funding more extensive cross-state research on the implementation and effects of reform.

The infrastructure of informal science education institutions presents an additional opportunity.

- *Opportunity 10: To expand informal science learning resources and enhance their contribution to school programs.* Although what is learned in informal science education is not well understood, its capacity to reach and motivate diverse, mass audiences is well established. Print and broadcast media, informal educational institutions, and educational associations thus appear to have a role to play in any broad-based attempt to broaden the pool of science learners, either as a complement to school programs or as an alternative route for individuals to pursue science interests. Various factors make informal science education a ripe area for further NSF investment: the growing public interest in this kind of learning opportunity, the increasing recognition that informal science settings can do things the schools can't do, the potential for engaging the home environment, and the cost-effectiveness of investments in this area. The Foundation can continue and extend the initiatives it has already undertaken, with special emphasis on supporting innovations, broadening the impacts of current successful programs, and cultivating new arenas (e.g., youth groups and recreational associations). It also has a substantial opportunity to explore more actively ways for informal science education to support school-based programs.

The opportunities we have just described provide one useful frame of reference for judging the likely contribution of current NSF (SEE) K-12 programs to the improvement of science education (we discuss a second frame of reference in the next section).

NSF (SEE) Programs in Relation to These Opportunities

As presently operated, SEE's current and projected programs (listed in Table S-1) are likely to address effectively some of the opportunities we have identified. However, SEE's programs are unlikely to take full advantage of all the opportunities for reasons that include the nature of program priorities, the lack of appropriate initiatives, and the limited resources available to SEE.

In the years following its reestablishment in 1983, SEE did not focus most of its support on a few carefully identified opportunities. Rather, it delineated broad programmatic areas, within which it has responded to proposals from the professional community and funded those that met the Foundation's criteria for merit. Thus, the nine SEE programs currently aimed at K-12 science education (listed in Table S-1) are each guided by a broadly stated program announcement, indicating an area of funding concern and some priorities within it. The result has been a wide range of projects that address many problems in science education and pursue many potentially promising ideas. That pattern has been changing more recently, however, as the Directorate has directed its funding increasingly toward specified targets, ones that correspond to several of the opportunities we have described. Special-purpose solicitations aimed at improving elementary science materials (within the Instructional Materials Development Program) and middle school teacher preparation (within the Teacher Preparation Program) are examples of activities that are more opportunity-oriented.

Currently NSF (SEE) supports at least one project related to each of the 10 opportunities, and invests heavily in projects related to a few (e.g., rethinking approaches to elementary science, expanding informal science education learning resources). Table S-2 summarizes the degree to which each opportunity is effectively addressed by current (and projected) programs.

As currently implemented, SEE's K-12 programs are unlikely to take full advantage of these opportunities for various reasons.

(1) Most of the programs have a broader, more diffuse goal than that implied by the opportunities. (The openness of these programs to a wide range of proposals may accomplish other important purposes, as we discuss in the next section.) Where they are more specifically targeted, SEE's programs come closer to addressing these opportunities, although some, like the Applications of Advanced Technology program, define the opportunity differently than we do.

Table S-1

CURRENT NSF (SEE) PROGRAMS AIMED AT K-12 SCIENCE EDUCATION*

Program (FY 1987 Funding, in millions**)	Objectives
1. Studies and Analysis ($2.2)	▪ Studies based on existing and new research data that provide systematic understanding of national trends and needs, effectiveness of educational alternatives, or other issues related to policy/planning.
2. Research on Teaching and Learning ($3.5)	▪ Basic and applied research on the most significant factors that underlie effective teaching and learning at all levels.
3. Instructional Materials Development ($9.4)	▪ Development of new and improved instructional materials and strategies.
4. Applications of Advanced Technology ($5.2)	▪ Research on the development and application of advanced educational technologies--particularly the computer--to science and mathematics education.
5. Informal Science Education ($11.4)	▪ Support for projects that ... encourage a rich environment for recreational learning (for both adults and children) ... to acquire science literacy and awareness.
6. Teacher Preparation ($5.0)	▪ Development of innovative approaches to preservice teacher preparation and creative materials to support teacher education; research on factors affecting teacher preparation.
7. Teacher Enhancement ($22.3)	▪ Support programs designed to enhance teacher effectiveness while serving as prototypes for other inservice projects.
8. Presidential Awards for Excellence in Science and Mathematics Teaching ($1.2)	▪ Provide national recognition for distinguished middle and secondary school teachers.
9. Science/Mathematics Education Networks ($2.0)	▪ The creation, evaluation, and exploitation of local, regional, and national networks designed to share information or disseminate resources related to teaching and learning.

* Not shown in the table are several projected activities: private-sector partnerships to improve K-12 science and mathematics education, assessment studies, and a "junior scholars" program.

** The total funding for K-12 science education in FY 1987--$62 million--represents approximately two-thirds of SEE's current budget and 4% of the total Foundation budget.

Table S-2

PROMISING OPPORTUNITIES FOR NSF'S INVESTMENT IN K-12 SCIENCE EDUCATION

	Estimated Extent to Which Current and Projected Investments Take Advantage of the Opportunity
Opportunities Related to the Search for Appropriate Content and Approach	
1. To reconceptualize K-12 mathematics curricula and associated instructional approaches	◪
2a. To rethink the approach to, and settings for, elementary science education	◪
2b. To recast the content of middle and high school science curricula	◪
3. To match science and mathematics education to different groups in a diverse student population	◪
Opportunities Related to the Strength of the Professional Community	
4. To bolster the support cadre serving science and mathematics teachers	◪
5. To help attract and prepare the next generation of qualified mathematics and science teachers (middle, high, and elementary specialists)	◪
6. To strengthen the informal science education community	◪
Opportunities Related to the Science Education "Infrastructure"	
7. To improve and expand science and mathematics education publishing capabilities	◪
8. To improve science and mathematics testing and assessment	◪
9. To provide content-related professional leadership for state science and mathematics education reform	□
10. To expand informal science learning resources and enhance their contribution to school-based programs	■

Key: Current and projected NSF (SEE) programs are (or will be) investing ...

□ = Little or nothing in relation to this opportunity.

◪ = A modest amount, related to some aspect of this opportunity.

◪ = A substantial amount in relation to several aspects of this opportunity.

■ = Heavily in relation to this opportunity as a whole.

(2) Some areas of opportunity are not given priority in current programs or plans for the future--science and mathematics testing (Opportunity 8) is the best example, but others can be cited, such as support for state science education reform (Opportunity 9).

(3) In some programs the current priorities work at cross-purposes to the directions implied by our opportunity discussions. For example, the current emphasis on innovative model development in the Teacher Enhancement Program and the corresponding lack of emphasis on leadership training are likely to detract from efforts to achieve the goal of developing a teacher support cadre, as described in Opportunity 4.

(4) Some opportunities are addressed partially, but in ways that are unlikely to add up to a satisfactory attack on the problem, because of either a lack of resources or an ineffectual approach. For example, development of short curriculum modules aimed at "filling content gaps" (through the Instructional Materials Development Program) is generating a number of creative ideas about possible curricular additions or revisions, but in aggregate these are unlikely to be comprehensive or numerous enough to reconceptualize science or mathematics content effectively as called for in Opportunities 1 and 2b.

(5) The overall level of resources available to SEE for K-12 activities does not permit it to take full advantage of all the opportunities.*

These factors do not prohibit SEE from continuing to evolve its K-12 programs further so that they take better advantage of these opportunities. We examine how this can be done later in this report.

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* Estimates of the resources required for a comprehensive effort related to each opportunity, under different overall strategic assumptions, appear in Appendix A and are discussed in Volumes 1 and 2.

CORE FUNCTIONS FOR NSF IN SCIENCE EDUCATION

Each of the opportunities just described implies that NSF invests in goal-directed activities. The success of these investments depends, in part, on the Foundation's support for other activities, which are focused less on a particular educational improvement goal than on the underpinnings for all improvement efforts: the interchange of ideas within the professional community, the development of information and knowledge about science education, and the encouragement of innovative ideas. Through these kinds of support, which we call "core functions," NSF (SEE) accomplishes two things: it prepares the science education community to take advantage of the opportunities and it aids its own process of designing effective initiatives. Simultaneously, the Foundation provides an essential national resource to the professional community.

As a base for strategic investment and as a resource to the science education community, NSF needs, on an ongoing basis, to: (1) promote effective professional interchange, (2) build the base of information and knowledge about science education, and (3) maintain support for innovation.

To some extent, these core functions can be, and are, carried out in the course of projects focused on particular opportunities. For example, efforts to reconceptualize the content of mathematics and science instruction rest, in part, on the participation of members of the scientific communities, as well as on the findings of research on science learning. However, to gain that knowledge and achieve the right kind of participation, an ongoing "intellectual infrastructure" must be maintained. For example, members of the scientific community who wish to make useful contributions to reconceptualizing the content of school instruction need to be familiar with schools and K-12 educational issues. Some form of open-ended support--intellectual "risk capital"--must also exist for scholars to pursue interesting avenues of inquiry. In other words, a critical mass of scientists (or scientifically trained professionals) and educational researchers, among others, must commit substantial amounts of time--even whole careers--to pursuing these issues.

These functions are especially appropriate for the Foundation. As the most centrally positioned and visible national-level institution concerned with education in the sciences, NSF (SEE) is able to orchestrate the interaction among diverse groups in the professional community. For example, along with scientific societies, it can attract members of the scientific communities across a wide range of scientific disciplines and facilitate their interaction with others concerned with science education. The Foundation's flexible discretionary funding can provide the intellectual risk capital needed to support advances in the state of the art.

We describe these functions in three categories below.

Promoting Professional Interchange

NSF is particularly well suited to foster ongoing professional interchange, especially between educators and members of the scientific community. Effective professional interchange depends on the presence of the right mix of participants, interaction between groups and individuals who do not naturally communicate with one another, and adequate mechanisms for exchanging information or materials.

- *Maintaining the link between educators and members of the scientific community.* The natural gap between educators and scientists can, and must, be bridged if education in the sciences is to reflect new knowledge, the structure of scientific thinking and the disciplines, or the process of science as it is practiced. NSF historically has been successful in bridging this gap, chiefly in the context of summer institutes for teachers and the large curriculum improvement projects of the 1960s and 1970s. Currently, NSF (SEE) places high priority on the involvement of scientists in the projects it funds, but this is not the only, or necessarily the most effective, way to encourage effective dialogue. Other kinds of collaborative arenas should be considered (e.g., science education centers or the equivalent). In addition, incentives that counter the forces for professional isolation should be created to help individuals from one community (e.g., scientists) participate in the other.

- *Developing networks within the science education community.* As noted earlier, the professional community is exceedingly diverse; yet communication among many kinds of groups and individuals is needed if change in complex educational systems is to result. At present, communication networks develop as a by-product of SEE's project funding, or sometimes by conscious design (e.g., through conferences, periodic gatherings of project directors, and telecommunication networks). Starting with SEE's grant recipients, NSF has the capability to establish or expand a number of communication networks beyond those it currently supports, in ways that are unlikely to result from normal channels such as professional society meetings. The greatest potential lies in communication between groups that have hitherto remained apart--for example, university-based cognitive researchers, industrially based technology developers, and practicing educators, who need to join forces more effectively if the promise of advanced technology is to be realized. NSF can do much to put these kinds of groups in touch with one another. Further experimentation with network mechanisms, meetings, and the creation of a central forum (e.g., a *Mosaic*-like journal for science education published by NSF) should be considered.

- *Establishing more effective mechanisms for disseminating materials and information.* NSF (SEE) and the science education community as a whole faces a perennial problem in making high-quality materials and research results available and useful to disparate groups within the community, especially front-line educators. The current approach of leaving dissemination up to individual project directors or the existing professional grapevine is

widely recognized as inadequate. Now, as a new generation of development projects and other improvement activities come to fruition, is an appropriate time for NSF (SEE) to develop better archiving and dissemination capabilities, drawing on available advanced technologies where necessary. To accomplish this, SEE should consider supporting regional/national information exchanges, reviews of existing materials and research, adaptation of existing mechanisms (e.g., the U.S. Department of Education's recently revised National Diffusion Network), and research on demand for high-quality materials.

Building the Base of Information and Knowledge About Science Education

NSF is the most appropriate national agency to stimulate the development of a cumulative base of information and knowledge about science learning, formal and informal science education systems, and the results of interventions in those systems. Generically, NSF needs to do three things in this regard: support research (or evaluation) that extends the state of the art, conduct or support inquiries into the way science education currently works, and facilitate the use of research or evaluation to influence educational practice. It should support these activities with regard to the individual learner and learning environment, the educational system as a whole, and interventions (particularly those undertaken by NSF) aimed at improving that system.

- *Investigating science learning and learning environments.* Understanding of the science learner and the process of science learning has increased greatly over the last decade (in part because of SEE funding). SEE's funding has helped to explore student misconceptions, problem-solving processes, and the possibilities of advanced technologies (e.g., intelligent tutors). Converging lines of scholarly inquiry point to the possibility of further advances in understanding how students interact with a "learning environment" (which includes teachers, other students, technologies, etc.). At the same time, SEE's renewed investments in materials development are generating "natural laboratories" in which new possibilities for examining teaching and learning arise. Further investment in these and related areas of scholarship will continue to provide the science education community with a basis for developing more sophisticated instructional approaches, as well as pointing the way toward promising interventions in the future.

- *Learning about science educational systems.* Similarly, the (formal and informal) education system as a whole should be a continuing subject of investigation. SEE has successfully supported investigations of this kind in the past few years by contributing to major national and international assessments of science and mathematics education and the development of indicator systems. In the same way that studies or assessment of the state of the field have illuminated possible areas for the Foundation to intervene in the current system, future investments in this area can refine this understanding by pursuing particular policy issues, further international comparisons, and the development of monitoring systems that are now in the design stage. SEE's

projected support for studies and analyses of various kinds represents a big step toward this goal.

- *Documenting and evaluating the results of NSF (SEE) interventions.* Aside from any benefits to project participants, all the activities supported by NSF (SEE) funds represent an opportunity to learn about the implementation and effects of particular interventions. Accordingly, to inform both its own future investments and the efforts of others, SEE needs to develop adequate descriptions and assessments of the activities it supports and their results or products. This kind of "learning from experience" can take many forms, ranging from formal third-party evaluations to systematic collection of anecdotal accounts. Currently, SEE derives information about each project from project directors' reports and self-evaluations, which vary greatly in quality, timeliness, and thoroughness. The results are inadequate for reasons that are well known: project directors lack the evaluation expertise, documentation takes time away from project work, etc. By judicious use of such devices as third-party documentors, cross-project comparative studies, and more extensive or focused use of principal investigators' meetings, SEE could develop better evaluative or descriptive information about the projects it funds.*

Supporting Innovation

NSF is one of the few national-level agencies with sufficient resources to encourage innovation in science education and to take advantage of unanticipated events. Serendipitous discoveries play as important a role in educational improvement as in scientific research, even though the task of improving educational systems generally demands more focused investment than does basic scientific research. NSF (SEE) can enhance the possibility of such discoveries by devoting some portion of its funding to open-ended investigations aimed at highly innovative research or development (not clearly related to targeted priorities), as well as by reserving some discretionary funding for important unanticipated events.

To some extent, this has happened as a result of SEE's current grants solicitation programs, which remain open to a wide range of ideas. The assistant director, division directors, and program officers also are allotted small amounts of money for contingencies that may arise. These practices should continue within each program or division. But, in addition, better mechanisms (special review processes, cross-program panels) need to be developed for handling the kinds of proposals that "fall through the cracks" in the program structure. Currently, these proposals do not receive a fair hearing.

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* During Phase II of this project, SRI will help develop and test procedures for SEE to use in evaluating its programs.

NSF (SEE) Programs in Relation to the Core Functions

Table S-3 summarizes the contribution of NSF (SEE) investments to the fulfillment of these core functions. Our conclusion parallels that for the opportunities:

> **SEE's current (and projected) programs and priorities fulfill some core functions better than others. All of these functions deserve careful consideration in SEE's planning for the future.**

As the table demonstrates, SEE is particularly effective in supporting studies and analyses of the state of science education. The Directorate's handling of documentation and evaluation or of dissemination and archiving, on the other hand, is conspicuously weak. These functions are admittedly difficult to carry out; nonetheless, SEE has paid little attention to them in the years since the Directorate was reinstated. Progress toward establishing the other functions has been more evident, but more effective mechanisms and a greater allocation of resources to these functions are necessary.

Failure to support all these functions adequately runs the risk of weakening the foundation on which any of SEE's initiatives builds. Education in the sciences at the K-12 level is too vast and decentralized an enterprise for an adequate intellectual infrastructure to develop on its own. Without specific incentives, many creative people will pass this field by for greener pastures. Without proper mechanisms for information exchange and interaction, whole segments of the professional community will remain unaware of what others are doing. Without a cumulative record of experience, NSF and the community as a whole will have few guideposts for further improvement efforts.

Table S-3

CORE FUNCTIONS AT THE K-12 LEVEL

	Estimated Extent to Which Current and Projected SEE Activities Fulfill These Functions
Fostering Professional Interchange and Participation	
▪ Maintaining the link between education and the sciences	◪
▪ Developing networks within the science education community	◪
▪ Establishing more effective mechanisms for archiving and disseminating materials and information	□
Developing the Base of Information and Knowledge	
▪ Investigating science learning and learning environments	◪
▪ Studying the state of science education systems	■
▪ Documenting and evaluating the results of NSF interventions	◪
Maintaining Support for Innovation and Unexpected Events	
▪ Providing support for innovative proposals (that don't fit existing program categories or priorities)	◪
▪ Participating in unanticipated events	◪

Key: Current and projected NSF (SEE) programs and policies support ...

□ = Little or no activity related to this function.

◪ = Substantial activity regarding several aspects of this function.

◪ = Modest activity regarding some aspect of this function.

■ = High activity addressing this function as a whole.

STRATEGIC INVESTMENT

To take full advantage of the opportunities we have described and thus contribute to the long-term goal of broadening the science learner pool, NSF needs to invest its funds strategically at two levels: first, through individual programs or initiatives framed to address particular opportunities, and second, through an overarching strategy that articulates the relationship between a set of initiatives and the long-term goal. As a base for this strategic investment, the Foundation must also invest in core function activities on a continuing basis so that it has the information to design initiatives properly and the professional community is adequately prepared to respond to these initiatives.

The business of contributing to K-12 educational improvement is different from the business of supporting scientific and engineering research, and it requires that the Foundation develop a "strategic capacity" for investing in science education over the long term. This kind of institutional capability to design and implement a coherent strategy for K-12 science education over 5 to 10 years has begun to develop within SEE, but it requires further development and the support of the Foundation as a whole, if strategic investments are to achieve the maximum payoff.

These components of strategic investment in science education, and the relationships among them, are displayed schematically in Figure S-3. Our conclusions with respect to each are as follows.

Initiatives

For those opportunities that NSF (SEE) chooses to address, it needs to design and implement initiatives that maximize the impact of the Foundation's dollars on the specified targets of opportunity.

By "initiative" we mean a programmatic attempt to support projects and other activities aimed at particular targets, using certain funding mechanisms, and embodying a particular philosophy or "theory" of change. In the course of examining each opportunity, we developed a set of initiatives that we believe deserve serious consideration as NSF decides how it will direct its grant programs.* These are not the only sensible initiatives that can be imagined; rather, they are meant to illustrate initiatives that are likely to achieve desired results.

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* The initiatives we developed--two or more per opportunity--are too numerous to describe here, nor can NSF support all of them. Each initiative is described and discussed in Volume 1. Strategically related sets of initiatives appear in Appendix A.

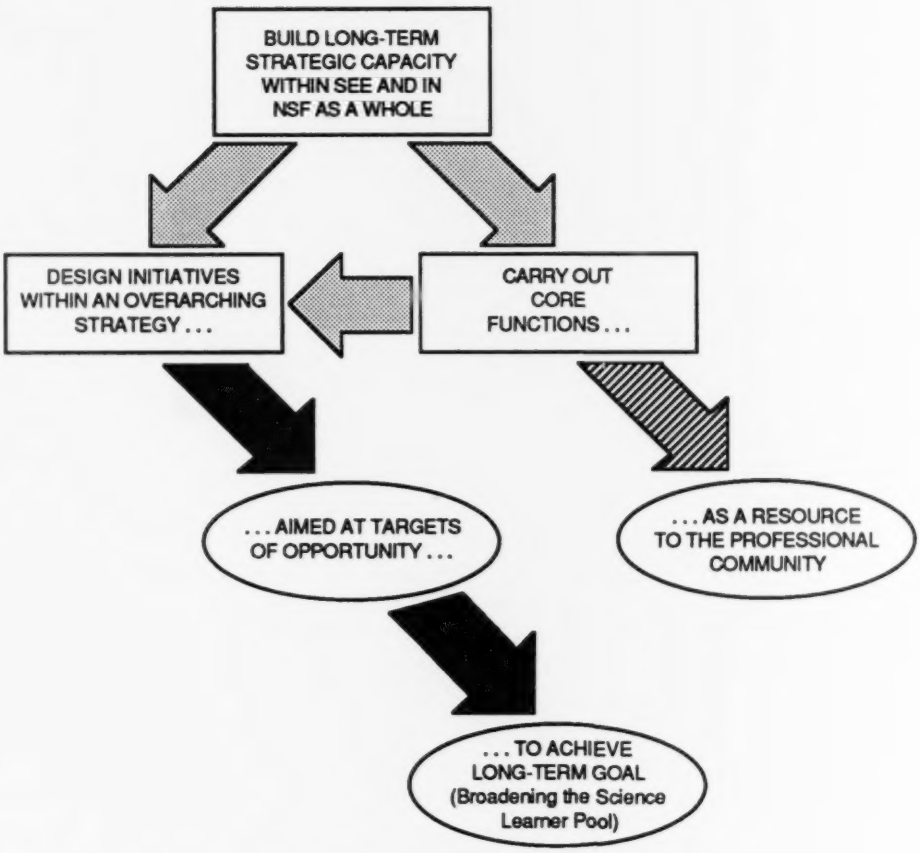
BUILD LONG-TERM STRATEGIC CAPACITY WITHIN SEE AND IN NSF AS A WHOLE
DESIGN INITIATIVES WITHIN AN OVERARCHING STRATEGY . . .
CARRY OUT CORE FUNCTIONS . . .
. . . AIMED AT TARGETS OF OPPORTUNITY . . .
. . . AS A RESOURCE TO THE PROFESSIONAL COMMUNITY
. . . TO ACHIEVE LONG-TERM GOAL (Broadening the Science Learner Pool)

FIGURE S-3 ELEMENTS OF STRATEGIC INVESTMENT IN K-12 SCIENCE EDUCATION

The process of designing a suitable initiative to address the opportunities described above parallels the process of identifying the opportunities themselves, only at a more practical and operational level. The central design considerations are: (1) Within the area of opportunity, what intervention targets are most critical and most closely related to the long-term goal of broadening the science learner pool? (2) What approaches to the problem are appropriate to NSF as a federal science funding agency, draw on NSF's unique capabilities, and are likely to maximize the direct and indirect impact of its dollars? (3) What approaches to the problem are most timely, given the activities of others, conditions in the field, state of knowledge about the problem, etc.?

Two other considerations--one philosophical, the other practical--also enter into the process of designing initiatives. First, what philosophy or "theory" of change is most appropriate to the opportunity (and most consistent with overall strategic objectives within the Directorate)? Second, what approaches are most feasible, in terms of both administrative requirements and political exigencies? Responsiveness to key constituencies--in Congress, the scientific establishment (including the NSF hierarchy outside of SEE), and the science education community (or segments within it)--is an extremely important consideration in this regard.

In the past few years, SEE has demonstrated an increasing ability to design sophisticated initiatives that take into consideration all these factors. A good example is the targeted solicitation, issued 2 years ago (with awards made in 1986), supporting the development of elementary mathematics programs that feature the calculator and the computer. It addressed a central conceptual and programmatic problem in K-6 mathematics (the organization of mathematics to reflect the impact of two key technologies), approached the problem in a way that was particularly appropriate to NSF (by inviting collaborative projects drawing on the mathematics education and mathematical sciences communities), and called for proposals at an opportune time (following a spate of reports calling for the reform of mathematics education, at a time when the two technologies were becoming widely dispersed in schools). Furthermore, the initiative was eminently practical; the implied philosophy of change--aimed at long-term rethinking of the K-6 curricular base--was appropriate to the state of knowledge and general progress toward reform goals.

Not all of SEE's recent initiatives are as well conceived. A recently announced "private sector partnerships" initiative provides a case in point. It calls for "activities by partnerships between business/industry, school systems, and other educational institutions ... to demonstrate ways in which community concerns can be translated into positive action to improve the quality of science, mathematics, and technology education" (*Federal Register*, March 17, 1987). Although the initiative is generally responsive to political constituencies and to the apparent interest of many private-sector firms to broaden their support for improving science education, the initiative is likely to spawn a diverse series of demonstrations that may contribute little toward the goal of broadening the pool or to any other strategic goal. The initiative is reactive, not strategic, and is more properly thought of as a mechanism that could be used to address any specific programmatic goal (in fact, the initiative invites proposals that relate to any of the existing K-12 programs).

With this (or any) initiative, much depends on how the initiative is implemented. The initial design, often reflected in a program announcement, is only one step toward strategic investment. For the initiative to be effective, SEE staff must implement it proactively, through activities such as the following: actively communicating with relevant professional audiences, encouraging proposals from highly qualified individuals and groups, "shaping" proposals, monitoring projects once they are under way, evaluating their contribution to strategic objectives, etc. SEE program staff do much of this routinely, but the limitations on their time preclude active monitoring and evaluation.

Overarching Strategies

The chances of achieving the goal of developing a broader pool of competent and interested science learners are increased if NSF develops an overarching strategy to guide the choice and implementation of initiatives so they are mutually supportive.

Individual initiatives will not the solve the overall problem, even though they may make an appreciable dent in some aspect of it. To contribute to a significant broadening of the science learner pool requires that NSF choose initiatives within an overarching strategy, so that they have the greatest likelihood of having mutually reinforcing effects on the various facets of the problem that need to be addressed. As pointed out earlier, the long-term goal will be reached only by simultaneously developing better content and more effective approaches, building professional capacity, and mounting interventions aimed at upgrading particular aspects of the current system.

An overarching strategy, as we define it, is an organizing rationale guiding diverse investments in K-12 science education. A strategy has the following components:

- An overall long-term goal, along with 5- to 10-year objectives that represent steps toward the goal.
- A coherent set of initiatives, aimed at improving (1) content and approach, (2) professional capacity, and (3) system functioning, that seem likely to achieve the strategic objectives.
- Exhibit a clear philosophy of educational change and NSF's relationship to it.

Aside from the likelihood of achieving mutually reinforcing effects, a coherent, publicly articulated strategy will enhance NSF's likely contribution to science education because it:

- *Sends clear signals to the professional community.* The Foundation will be able to explain more easily to the outside world what it seeks to accomplish, especially to the diverse groups in the science education community that can organize their energies around strategic objectives to achieve "critical mass" effects. NSF will also be able to defend the fact that it cannot please every constituency.

- *Manages multiple interests and limited resources.* Given the number of problems and the scope of science education activities, the limited resources available for K-12 science education improvement are more likely to achieve significant impacts if they are invested strategically.

- *Responds to the concerns of Congress and OMB.* Legislative and executive branch audiences do not understand what NSF is committed to accomplishing in precollege science education or the degree of its commitment at this level. Without a declaration of mission and strategy, neither Congress nor OMB knows what expectations to hold or how to justify resource allocations.

- *Avoids the problem of program proliferation.* In the absence of a strategy, NSF may face the situation of the latter 1970s, when numerous education programs were legislated, to the point that Congress and others saw little coherence in the Foundation's science education programs.

- *Enhances productivity within NSF.* The internal fine-tuning of program plans, the orientation of new staff, and the day-to-day operations within SEE (and other parts of NSF that may be involved) will be improved if staff can see how their work fits in with, and is justified by, a larger educational strategy.

Two contrasting strategies underlie NSF's (SEE's) current programmatic efforts in K-12 science education--one emphasizing incremental improvements in the short term, the other aimed at longer-term, more fundamental change. Although both are necessary, NSF (SEE) should declare one (or an alternative) as its primary strategy.

Currently, one can discern two contrasting strategies at work within and across SEE programs; so far, these have been most clearly articulated at the level of individual programs. Each presents a fundamentally different philosophy of educational change and NSF's role in the change process:

- *Incremental improvement strategy.* This strategy emphasizes upgrading current formal and informal educational systems, primarily through investments that achieve widespread impacts in the short term. For example, support for collaborative ventures with publishers to improve science course materials, inservice teacher education, and national children's broadcasts in science and mathematics reflect this strategic approach.

- *Fundamental change strategy.* This strategy aims at exploring the possibilities, extending the state of the art, and searching for new approaches that can radically improve education over the long term. Research on science learning environments, exploration of technological innovations, and long-term leadership development illustrate this strategic approach.

The two strategies have historically contended to be the guiding principle behind the Foundation's educational investments, and an unstated tension between the two continues at present. Programs such as Applications of Advanced Technology and, to some extent, Research on Teaching and Learning aim at long-term change in understanding and technical capability. Others, such as Teacher Enhancement or Presidential Awards for Excellence in Science and Mathematics Teaching, emphasize shorter-term intervention in the current system. Still other programs fall uneasily in between.

In the last few years, one of the two strategies has begun to emerge as the predominant direction for SEE's K-12 funding. On balance, most of SEE's funds are awarded to projects aimed at achieving incremental improvements in the short term, more than at fundamental reconceptualization or restructuring aimed at the long term. Emphasis is shifting to the elementary and middle school levels, with the bulk of funding devoted to improving curriculum and teacher education.

In its present form, SEE's overall strategy is not as well articulated or as coherent as it could be at the Directorate level (even within some programs the predominant strategy has not been clarified). Each of the nine current K-12 programs embodies a strategy of its own; collectively, the programs are designed to address the major components of the science education system. But because the strategies of different SEE programs diverge considerably and do not relate obviously to one another or to a long-term goal, external audiences are unlikely to know what NSF is trying to accomplish. Within SEE (and NSF as a whole), a statement of K-12 strategy has yet to be articulated clearly enough to aid in the design of new initiatives or other procedural adjustments.

Currently, SEE and the Foundation leadership are taking steps toward developing a clearer mission and strategy for the K-12 level, as part of an approach to science education at all levels. The Foundation has recently submitted to Congress the first annual update of its 5-year strategic plan for science education improvement, part of which deals with plans for K-12 investments. A Foundation-wide Task Group on Education and Human Resources is currently at work on a report that will establish a planning framework to guide NSF's educational investments at all levels over the next few years. But the results of these efforts, so far, fall short of the clarity or direction that is needed.

What would a clearer and more coherent strategy look like? We sketch below two scenarios that illustrate possible outcomes of strategy development. The first can be thought of as an extension or elaboration of current tendencies within SEE. The second is an alternative that makes up for the shortcomings of the first, but represents a different set of trade-offs.

The Incremental Improvement Strategy

The incremental improvement strategy seeks to broaden the pool of science learners by emphasizing short-term investments with potential for wide impacts, such as professional upgrading (with emphasis on teachers now in place) and support for programs that strengthen and diversify the science education alternatives in formal and informal learning settings.

The guiding philosophy of this strategy holds that achieving widespread impacts on formal and informal science educational systems in the near term is the best way to broaden the pool of competent and interested science learners up to the age of 18. This strategy assumes that the most effective way to reach students is to make improvements in existing educational systems--wherever NSF has points of leverage. Critical current needs in science education drive this conception of NSF's role. In its attempt to orchestrate or stimulate changes that will have systemwide ramifications, the Foundation seeks to become a closer partner of the educational establishment.

The incremental improvement strategy seeks to promote the development of a broader pool of science learners by aiming at the following primary objectives over the next 5 to 10 years:

(1) The creation of a wide array of challenging new curricular alternatives, appropriate to a broad pool of learners at all K-12 levels.

(2) The development of extensive support networks for mathematics and science teachers now in service or newly entering the profession, to help them adapt their current instruction and curricula as well as take advantage of new curricular alternatives and informal science education opportunities.

(3) The expansion of informal science education programs aimed at diverse student needs at the K-12 level.

(4) Mobilization of "educational infrastructure" institutions (in particular, publishers, testing firms, and state education agencies) in support of these improvements.

This strategy places emphasis on system intervention and the development of professional resources, especially within the teacher force, as shown schematically in Figure S-4. The following mix of investments makes most sense within this strategy:

- *Investments in improving content and approach.* Upgrade content through creating alternative courses and multiyear programs in both mathematics and science, starting with the elementary and middle grades; support incremental improvements in content by working through those institutions that exert the greatest control over the curricula used by the majority of students and teachers (e.g., publishers--see investments in systems upgrading); support efforts to promote exemplary programs for underrepresented groups, along with direct support.

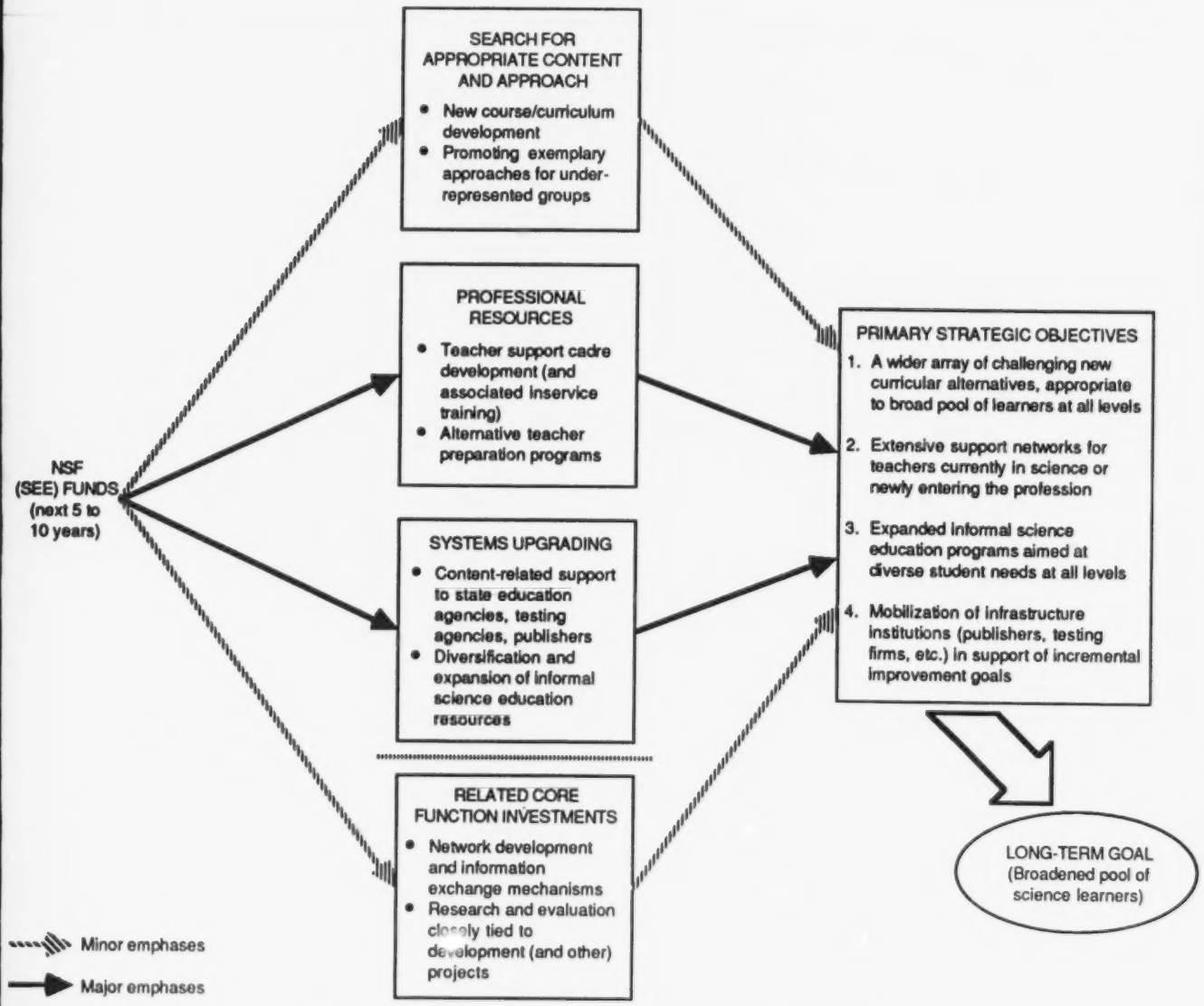
SEARCH FOR APPROPRIATE CONTENT AND APPROACH
• New course/curriculum development
• Promoting exemplary approaches for under-represented groups
PROFESSIONAL RESOURCES
• Teacher support cadre development (and associated inservice training)
• Alternative teacher preparation programs
SYSTEMS UPGRADING
• Content-related support to state education agencies, testing agencies, publishers
• Diversification and expansion of informal science education resources
RELATED CORE FUNCTION INVESTMENTS
• Network development and information exchange mechanisms
• Research and evaluation closely tied to development (and other) projects
NSF (SEE) FUNDS (next 5 to 10 years)
PRIMARY STRATEGIC OBJECTIVES
1. A wider array of challenging new curricular alternatives, appropriate to broad pool of learners at all levels
2. Extensive support networks for teachers currently in science or newly entering the profession
3. Expanded informal science education programs aimed at diverse student needs at all levels
4. Mobilization of infrastructure institutions (publishers, testing firms, etc.) in support of incremental improvement goals
LONG-TERM GOAL (Broadened pool of science learners)
Minor emphases
Major emphases

FIGURE S-4 INCREMENTAL IMPROVEMENT STRATEGY

- *Investments aimed at strengthening professional resources.* Concentrate on improving teachers now in service (or newly entering) by heavily investing in the individuals and networks that provide them support (training, advice, assistance in the selection of materials); complement these investments with selective efforts to improve the long-term supply of entering teachers, especially through alternative preparation routes and support to the teacher education cadre.

- *Investments aimed at systems upgrading.* Mount simultaneous initiatives aimed at the publishing establishment, testing agencies and firms, and state education policymakers to alter their effects on what is taught and how it is taught; support an expansion of informal science education resources in different arenas; provide incentives for increasing the contribution of these resources to school programs.

- *Related core function investments.** Put emphasis on network development and information exchange mechanisms within the professional community; support research on learning and learning environments that is closely related to development projects, along with increased efforts to evaluate and document NSF-funded projects; emphasize research syntheses and interpretation to encourage the use of research by front-line practitioners; support extensive studies and analyses of both formal and informal science education systems; maintain a low level of support for open-ended innovation.

The advantages of this strategy are numerous--chief among them, the fact that it is practical and likely to lead to broad, albeit modest, improvement for many teachers and students. It would be widely visible to the public and its representatives in Congress. Because it extends a philosophy implicit in the current evolution of most SEE programs, the strategy represents the "line of least resistance," which contributes further to its practicality.

But there are important trade-offs implied by going this route. Foremost among them, NSF (SEE) will forgo many (though not all) chances to invest in breakthrough ideas for the future--for example, ideas that might result from heavy funding for efforts to reconceptualize curricular content, R&D in advanced technologies, and research on learning and teaching, among others.

Also, this strategy stretches the limits of NSF expertise by requiring individuals with extensive backgrounds in educational change, the workings of institutions in the educational infrastructure, etc. In addition, members of the scientific community would be less drawn to initiatives explicitly aimed at widespread impact on educational systems. Finally, the strategy is likely to incur high costs, even with highly leveraged investments, if NSF is to attempt to achieve widespread impacts.

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* Not all core function investments relate specifically to a particular strategy, but instead underlie any strategy. Nonetheless, each strategy has different requirements for core functions.

These are serious drawbacks and they lead one to give the alternative strategy careful consideration.

The Fundamental Change Strategy

The fundamental change strategy emphasizes broadening the pool of science learners by exploring the possibilities for radically restructuring what is taught, creating fundamentally different learning environments, and investing heavily in leadership development and the next generation of teachers.

The second strategy, schematically represented in Figure S-5, assumes that K-12 science education, as currently conceived and practiced, is fundamentally inadequate. From this point of view, incremental improvements will be insufficient to achieve the goal of broadening the pool of competent, interested science learners. Instead, new conceptions of K-12 science and mathematics content, as well as breakthrough discoveries about teaching and learning, are necessary that have the potential to restructure what is taught and how it is taught, in ways that capture the national imagination.

This strategy aims at the following primary objectives over the next 5 to 10 years:

(1) The development of new conceptions of content for, and approach to, K-12 science and mathematics education (in formal and informal settings) that better serve the goal of developing a broad pool of science learners. The strategy assumes NSF will try to develop, insofar as possible, a national professional consensus around these conceptions.

(2) The emergence of a new generation of leaders at all levels in the science education community who can communicate the new conceptions broadly and persuasively within the educational establishment and the scientific community.

(3) The development and testing of models for teacher preparation and continuing education that promise to attract and equip teachers to carry out the new conceptions of science education.

(4) The creation and demonstration of curricular/instructional prototypes that translate the new conceptions into action in a variety of educational settings.

To stimulate the kind of restructuring involved in this strategy, NSF stands apart from the existing educational establishment and brings in new perspectives from academia, the scientific establishment, industry, and others. The Foundation provides leadership and supports leading-edge developments that affect the future direction of education in the sciences. The driving force behind this conception is the demonstrated capacity of the Foundation to mobilize diverse intellectual talent and

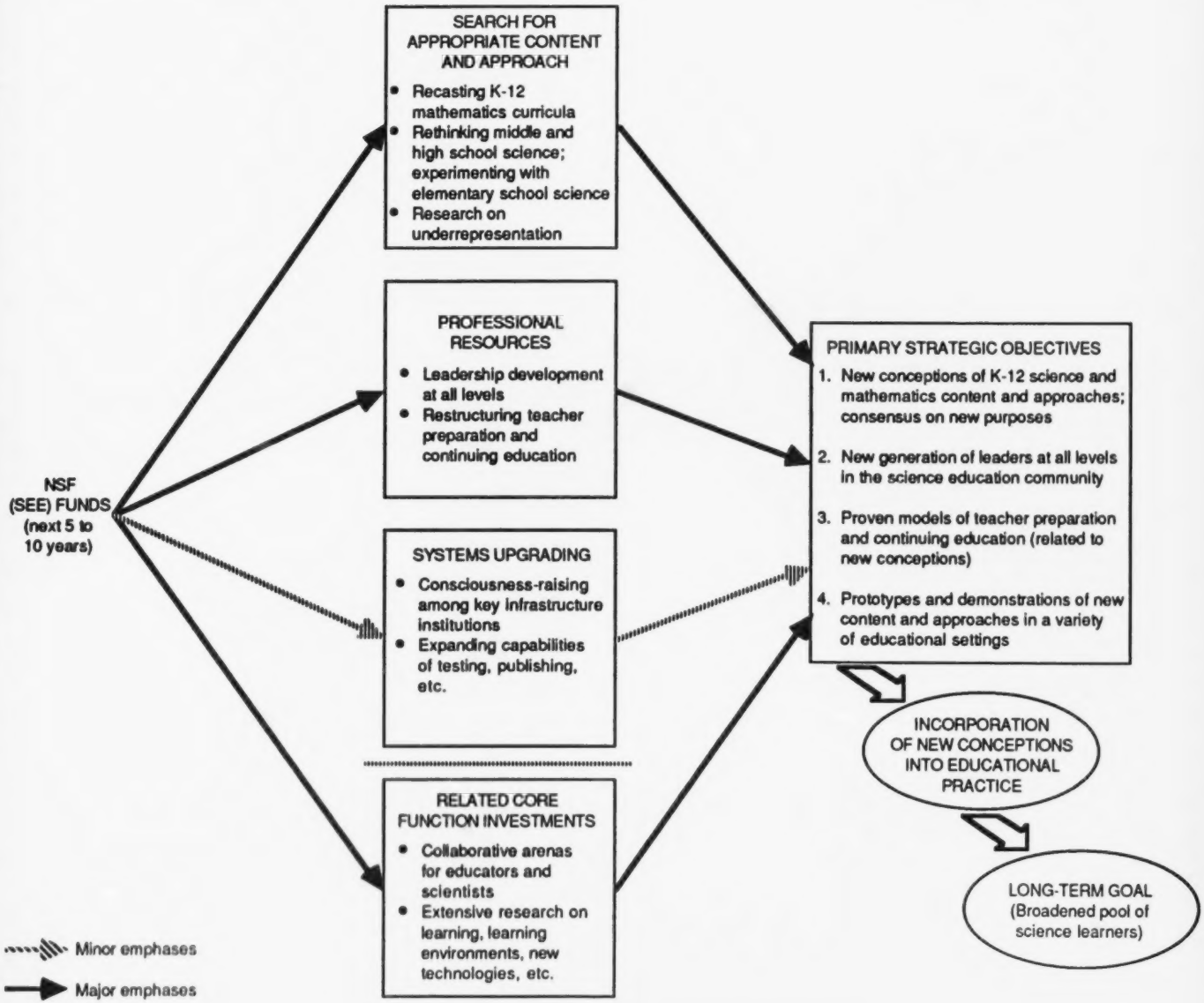
SEARCH FOR APPROPRIATE CONTENT AND APPROACH
• Recasting K-12 mathematics curricula
• Rethinking middle and high school science; experimenting with elementary school science
• Research on underrepresentation
PROFESSIONAL RESOURCES
• Leadership development at all levels
• Restructuring teacher preparation and continuing education
SYSTEMS UPGRADING
• Consciousness-raising among key infrastructure institutions
• Expanding capabilities of testing, publishing, etc.
RELATED CORE FUNCTION INVESTMENTS
• Collaborative arenas for educators and scientists
• Extensive research on learning, learning environments, new technologies, etc.
NSF (SEE) FUNDS (next 5 to 10 years)
PRIMARY STRATEGIC OBJECTIVES
1. New conceptions of K-12 science and mathematics content and approaches; consensus on new purposes
2. New generation of leaders at all levels in the science education community
3. Proven models of teacher preparation and continuing education (related to new conceptions)
4. Prototypes and demonstrations of new content and approaches in a variety of educational settings
INCORPORATION OF NEW CONCEPTIONS INTO EDUCATIONAL PRACTICE
LONG-TERM GOAL (Broadened pool of science learners)
Minor emphases
Major emphases

FIGURE S-5 FUNDAMENTAL CHANGE STRATEGY

its close connections to segments of the professional community that have potential for innovation in education (including the cognitive sciences and information technologies). In this scenario, the following mix of investments makes most sense:

- *Investments aimed at improving content and approach.* Support for a national reexamination of what is taught in middle and high school science, the approach to elementary science, and K-12 mathematics curricula; heavy exploratory investment in advanced technologies as part of this reexamination; national dialogue among various segments of the professional community about appropriate purposes and guiding conceptions for science education; research on underrepresentation and promising approaches to combat it; prototype development of radically different K-12 mathematics and science education programs.

- *Investments in strengthening professional resources.* Leadership development activities aimed at attracting new kinds of formal and informal science educators to prominent positions within the profession; funding for support cadre development (as in the previous strategy, but given less emphasis here); thorough reexamination of trouble spots in the teacher education process and attempts to demonstrate new approaches.

- *Investments in system upgrading.* Exploration of alternative publishing routes for innovative materials; R&D on the "textbook of the future"; national dialogue among state policymakers, others in the educational establishment, private-sector vendors and employers, and members of the science education community about purposes for science education, guiding conceptions, and frameworks; research and evaluation on the effects of informal science education.

- *Related core function investments.** Creation of collaborative arenas (e.g., science education centers or the equivalent) in which educators, scientists, and others pursue work related to science education; increased incentives for participation of scientists and engineers in K-12 education; network development, especially among those not currently in the science education mainstream (e.g., industry-based technology developers); creation of an NSF-based science education journal, parallel to *Mosaic*; extensive research on learning and learning environments, and analyses of the system aimed at projected future conditions; a limited program of evaluation research, concentrating on projects that experiment with content and approach; substantial funding for open-ended efforts at innovation.

By contrast with the incremental improvement strategy, the greatest amount of funds would be allocated to improving content and approach, as well as leadership

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* Not all core function investments relate specifically to a particular strategy, but instead underlie any strategy. Nonetheless, each strategy has different requirements for core functions.

development within the professional community. Relatively few resources would be devoted to interventions in the current educational infrastructure.

The fundamental change strategy is more likely to generate intellectual excitement within the scientific community and the university-based community of science and mathematics educators, as well as others who form the "intellectual infrastructure" for education in the sciences (school-based educators who become involved in research or development, developers outside of the schools, some informal science educators, etc.). By so doing, the strategy has good prospects for broadening the professional community by attracting talented people who now have little role in it. The coalitions stimulated by NSF's funding and involvement are also likely to create exciting new forms of, and prototypes for, science education.

But this strategy, too, presents difficult trade-offs. By maximizing investment in ideas that go beyond the capabilities of current educational systems, it is not clear that the ideas will make their way into widespread educational practice, even though they may be implemented in "lighthouse" schools and school districts. Whether the majority of schools will eventually adopt what NSF's leadership produces depends on many things--for example, how widely diffused among the leadership of the professional community the ideas become or how feasible and compelling the new approaches are. The strategy also has the danger of appealing more to the scientific community than to Congress or to practicing educators, who want help with the pressing and practical problems before them now.

We do not believe that either of these strategies is clearly superior (nor do we assert that these are the only two that could be imagined). It is also not a question of choosing one strategy to guide all of NSF's educational investments; there will always be a need for a mixture of investments, some aimed at incremental involvement, others at fundamental changes. The important question is one of emphasis, given limited resources. There are not enough resources under any believable scenario for the Foundation to fully implement both strategies (see Appendix A for estimates of the resources required). Declaring one strategy to be the primary direction for the Foundation's educational investments thus concentrates resources in one direction, but it does not preclude investments guided by the other philosophies. Having a primary strategy provides guidance about the way a marginal increase in funding should be spent, as well as a basis for adjusting current programs where their emphases and contribution to strategic objectives are unclear. It also helps to explain and justify current and projected budget allocations for these investments.

The best strategy will be one that SEE leaders feel comfortable with and can convince other NSF leaders to support and articulate within and outside the Foundation.

Whichever direction NSF (SEE) chooses for its strategy, the gain for the nation's K-12 science education is likely to be substantial. The two strategies represent a different balance of investments in content and approach, strengthening the professional community, and system intervention; thus, each is comprehensive and seeks solutions with systemwide ramifications. Each strategy is implemented by supporting

a coherent set of initiatives related to the opportunities described earlier. The available evidence regarding the effects of different types of investments, the opportunities before the Foundation, and the analysis of NSF's most suitable roles, indicates that each strategy in its own way promises to maximize the Foundation's "return" on its educational investments at the K-12 level.

Strategic Capacity

To implement strategies of the sort just described requires several things: (1) SEE leaders, in conjunction with SEE staff and NSF leadership, must articulate--within NSF and externally--the strategy that they feel most comfortable with; (2) NSF must request (and be granted) sufficient resources to carry out such a strategy; (3) SEE staff must design and implement appropriate initiatives, along with necessary adjustments in staffing, programs, and procedures; (4) SEE staff, with the support of NSF as a whole, must assume a proactive posture in pursuit of strategic objectives.

These steps require that SEE and the Foundation as a whole build and maintain a "strategic capacity" for investing in educational improvement over the long term. This capacity--an institutional capability to invest funds strategically--includes: a centralized home base within the Foundation, the right staff expertise, continuity of resources, procedures and policies that enable SEE staff to be proactive, and support from the Foundation's top leadership.

SEE has evolved rapidly since its reinstatement 3 years ago and is developing a capacity for investing strategically in K-12 science education. The Education Directorate needs to continue that evolution, with the full support of the Foundation as a whole.

NSF's capacity for addressing problems in K-12 science education, located in the Foundation's Education Directorate, has developed rapidly from virtually nothing during the early 1980s when the former Science Education Directorate was completely dismantled. After an initial period of start-up difficulties following the Directorate's reinstatement in 1983, SEE moved quickly to reestablish its program structure, rebuild its staff, and process the flood of proposals that came its way. Its progress to date is remarkable, considering the extent of the disruption--in terms of discontinued relationships, departed staff, and lost records.

Most important, SEE has increasingly assumed a strategic posture in K-12 science education. Reflecting this change, SEE has used more "targeted solicitations" within several of the programs and has more clearly defined priorities in others. Accompanying the movement toward focused investment, SEE has become increasingly proactive, in both overt and subtle ways. Many program officers routinely encourage appropriate proposers. Staff have made overtures to a number of the important groups in the professional community to explore possibilities for mutual collaboration (for example, a recent meeting of foundations and scientific societies involved in supporting professional networks). Some program and divisional staff involve a wide range of professionals in planning and have hosted initiative design conferences to

help chart future directions for investment. These practices represent an excellent beginning in the direction of strategic investment.

But SEE's strategic capacity must develop further in this direction. The evolution to date and the need for further improvement are briefly summarized below with respect to each aspect of capacity.

Organizational home base--SEE provides a suitable home base within NSF for staff with K-12 educational expertise. The centralization of such staff in a single directorate is a prerequisite for coordinated strategic investments and should continue. Although this point may seem obvious, the matter has been debated over the years and remains an issue, especially in light of the Foundation's plans to disperse budgetary control over undergraduate-level educational investments among all research directorates.

Staff expertise--SEE has assembled a diverse professional staff with many of the competencies necessary for dealing effectively with K-12 science education systems. For reasons that are understandable (the loss of permanent staff in the early 1980s, the need to gear up quickly, the difficulty of luring good people away from their current employment), SEE has yet to attract a sufficient cadre of permanent staff with grantmaking expertise, good substantive backgrounds, and familiarity with educational systems: approximately two-thirds of SEE's professional staff who deal with K-12 issues are rotators, which contrasts sharply with the 1-in-3 average across other directorates in the Foundation. Rotators bring enthusiasm and recent connections with the field, but they lack grantmaking expertise; their rapid turnover makes it more difficult to ensure continuity over time.

If SEE is to undertake a more strategic presence in K-12 science education along the lines we have described, further adjustments and additions to the staff will have to be made. Under either strategy, for example, additional staff members with mathematics education expertise would be required to address opportunities such as revamping the K-12 mathematics curricula and to match the heavy emphasis on mathematics education at the elementary and secondary school levels. The number of new staff required depends in part on the amount of funds to be disbursed, but it is also possible that SEE has too few staff (even at current funding levels) for the proactive activity implied by either strategy.

Continuity of resources--For strategic investment to succeed, NSF will need to maintain a level of funding over a period of years (e.g., 5 to 10) that corresponds with plans and objectives for K-12 education improvement. This is admittedly a difficult thing to manage in an era of concern over budget deficits; however, vehicles for securing long-term funding do exist (such as the Foundation's current request for a 5-year appropriation) and should be vigorously pursued.

The amount and continuity of funding for K-12 science education reflects the relative priority placed on support for different levels of education. Because this report deals only with investments at the K-12 level, it has little to say about relative priorities between this and higher levels of education. However, it should be

pointed out that the pattern of budget requests for K-12 activities from the Foundation since 1983 suggests a reluctance on the Foundation's part to increase its investments in this level (even the current budget request, which reflects sizable increases for scientific research and for education as a whole--mostly undergraduate activities to be lodged outside SEE--has little real increase for K-12 activities). The success of any overarching strategy in K-12 science education is dependent, in part, on the amount of resources allotted to it.

Procedures and policies affecting proactivity--Both within SEE and in the Foundation as a whole, procedures and policies that bear on the proactivity of staff (and the Foundation as a whole) deserve careful examination, in recognition of the differences between support for education and support for scientific or engineering research (there are some parallels between education and engineering that should be examined). Although this study concentrated on an analysis of opportunities, alternative initiatives, and strategies, it became obvious that there were important operational implications of the alternatives under consideration. In particular:

(1) The application of merit review procedures in various areas of educational investment may be different from those used by other parts of the Foundation. Alternative arrangements (such as standing review panels, which can provide not only expert external review but some continuity of vision in project funding decisions over time) should be actively considered and applied wherever they make sense.

(2) Policies governing staff ceilings (set by NSF outside of SEE) should be carefully reviewed to determine whether they permit SEE enough staff to engage in the kinds of proactive outreach that are implied by the initiatives and strategies we have been discussing.

(3) Expectations for the use of staff time within SEE--e.g., the balance of time devoted to paperwork, proposal review as opposed to monitoring ongoing projects, designing new initiatives, cultivating potential collaborators, etc.--need to be adjusted if K-12 educational investments are to become more strategic. This is not to ignore the real time pressures placed on SEE staff by the large numbers and complexity of proposals they receive. But there are ways to streamline the proposal review process (e.g., through more vigorous use of preliminary proposals) and to augment staff capacity (e.g., by use of third parties for project monitoring and initiative design activities). New rotating staff can be brought in with a clearer set of expectations about other responsibilities besides proposal review. SEE should experiment more actively with these kinds of activities.

Support from Foundation leadership--Although they are coordinated and implemented by SEE, strategic investments in K-12 science education are more likely to succeed if they receive the active support of the Foundation as a whole, especially its leadership. After a period of paying relatively little attention to science education in the first half of the 1980s, NSF's leadership has recently taken more

interest in educational matters, especially those related to undergraduate and doctoral or postgraduate study. A Foundation-wide task force on education and human resources (a theme within the Foundation's FY 1988 budget request, as well) is currently at work attempting to clarify the Foundation's role in all areas of science education.

But despite these signs of renewed interest in its educational mandate, the Foundation as a whole is sending mixed signals regarding K-12 science education. If NSF's top leadership is committed to developing an effective strategic capacity in K-12 science education, it should move quickly, in conjunction with SEE, to develop more effective and consistent statements of mission and strategy and to build them into Foundation-wide policy on educational investments. At present, the statements of educational mission developed inside and outside of SEE do not agree; updated 5-year plans recently forwarded to Congress have lacked a clear statement of strategic approach along the lines described earlier in this report. Budget submissions also have not reflected a commitment to K-12 science educational improvement.

NSF top leadership and the National Science Board (NSB) have a role in helping to articulate the strategy in K-12 science education, which they should exercise more vigorously. The absence of public commentary by the NSB on K-12 science education issues since its report *Educating Americans for the 21st Century* (1983) is notable. By helping to enunciate the Foundation's strategies to political and professional groups, as well as to the public, these bodies may obviate congressional pressures on the one hand; on the other, they may help to mobilize the relevant professional communities behind the Foundation's educational mission.

NSF as a whole, not SEE alone, will need to exercise leadership in the scientific community on behalf of K-12 science education if it wishes to establish a more effective strategic presence in this area.

Many of the Foundation's primary constituencies (in the scientific community) do not necessarily recognize the importance of science education investments, least of all at the K-12 level. The reasons for this state of affairs go deep into the history and tradition of the Foundation, and deeper still into the society at large. Assuming the Foundation wants to contribute to broadening the pool of young science learners, it will require the concerted effort of committed individuals at all levels in the Foundation to educate the scientific community to accord K-12 science education the prominence it deserves.

Appendix A

INITIATIVES TO IMPLEMENT OVERARCHING STRATEGIES

The following tables list initiatives we developed for NSF (SEE) to improve K-12 science education under two different strategies. The first emphasizes investments aimed at incremental improvements through widespread impacts on current educational systems, and the other emphasizes efforts to promote more fundamental changes in the structure of science education over the long term. Each strategy includes a comprehensive set of initiatives that collectively address the 10 opportunities described in the report. In a few cases, the same initiative appears in both strategies; more often, different initiatives related to each opportunity appear in each strategy that reflect the underlying strategic philosophy. (We have noted within the tables the opportunity or core function category to which each initiative corresponds.)

Resource estimates indicate the scale of investment that would be necessary to achieve the targets of opportunity. These estimates are based on analyses discussed in *Volume 1 - Problems and Opportunities* and *Volume 2 - Groundwork for Strategic Investment*. Resource estimates reflect the following assumptions:

(1) Estimates indicate the level of SEE investment over the next 5 years, even though some initiatives would require a longer time frame for completion.

(2) Estimates do not include current SEE obligations for future fiscal years. The amounts in the table would be allocated to existing SEE programs, or in some cases to newly created ones, over and above what these programs require to meet existing obligations.

(3) The figures indicated in the tables do not show the amount for each initiative where a set of initiatives relates to a particular opportunity or core function. See Volumes 1 and 2 for details about each initiative's resource requirements and the basis for these estimates.

Table A-1

INITIATIVES THAT IMPLEMENT AN INCREMENTAL IMPROVEMENT STRATEGY

Area of Opportunity/Initiatives	Estimated Resources (Over 5 years)
*Investments aimed at improving content and approach**	
a. Develop software tools for learning mathematics; expand support for current efforts to develop standards (Opportunity 1).**	$25-33 million
b. Fund limited program of field-based experiments with new conceptions of middle and high school science content (Opportunity 2b).	$25-30 million
c. Support efforts to promote exemplary models for reaching underrepresented groups; develop curriculum materials targeted to underrepresented groups; support talented members of underrepresented groups in intensive science experiences (Opportunity 3).	$30-43 million
Investments aimed at strengthening professional resources	
a. Put in place an extensive "support cadre" (lead teachers, curriculum specialists, and others) that will provide inservice training, advice, and other forms of assistance to current or newly entering mathematics and science teachers--especially at the middle and high school levels; support development of leaders and change agents at the elementary school level (Opportunity 4).	$220-244 million

* Efforts to improve content and approach through collaborative projects with publishers are listed on page 49 under "Investments aimed at systems upgrading."

** Investments in software listed here do not include technology development that occurs as part of collaborative publisher projects, research on learning and learning environments, or the development of advanced technologies for the future.

Table A-1 (Continued)

Area of Opportunity/Initiatives	Estimated Resources (Over 5 years)
Investments aimed at strengthening professional resources (continued)	
b. Develop alternative preparation and retraining programs; support and upgrade science and mathematics teacher educators; some investment in new approaches to teacher education and teacher incentives (Opportunity 5).	$55-75 million
c. Study the current state of the informal science education field (Opportunity 6).	$4-5 million
Investments aimed at systems upgrading	
a. Engage publishers in ambitious efforts to improve mathematics and science materials at the elementary and middle school levels, to be followed by high school level; seed the science and mathematics tradebook market for young audiences (Opportunity 7).	$50-60 million
b. Stimulate national dialogue on testing policy and support efforts to improve prominent tests and assessments now in use (Opportunity 8).	$10-15 million
c. Stimulate national dialogue on state science education reform; provide technical assistance to state-level planners and policymakers; support cross-state research to help states learn from each other's reform efforts (Opportunity 9).	$15-21 million
d. Expand informal science learning resources in broadcast, museum, and recreational association arenas; support experiments with making these resources more available to schools (Opportunity 10).	$100-130 million

Table A-1 (Concluded)

Area of Opportunity/Initiatives	Estimated Resources (Over 5 years)
Related core function investments	
a. Professional interchange: support network development within the professional community, with emphasis on practicing science educators; develop effective archiving and dissemination mechanisms; incentives for scientists' participation; research on demand for currently available high-quality materials.	$39-50 million
b. Knowledge building: support research, monitoring, and policy studies emphasizing the functioning of formal and informal systems; fund research on learning and learning environments that is closely related to development projects and to new technologies that are widespread in the schools; increase efforts to evaluate and document NSF-funded projects; support research syntheses and interpretations to encourage use of research by front-line practitioners.	$55-64 million
c. Support for innovative ideas, unanticipated opportunities (as part of each K-12 science education program).	$26-30 million
TOTAL:	$654-800 million

Table A-2

INITIATIVES TO IMPLEMENT A FUNDAMENTAL CHANGE STRATEGY

Area of Opportunity/Initiatives	Estimated Resources (Over 5 years)
Investments aimed at content and approach	
a. Support efforts to reconceptualize K-12 mathematics through curriculum prototype creation and standard-setting (Opportunity 1).*	$40-50 million
b. Fund basic and conceptual research on alternative approaches to elementary science along with large-scale field trials of these approaches (Opportunity 2a).	$48-62 million
c. Stimulate a national reexamination of what is taught in middle and high school science through national task forces and field-based experimentation (Opportunity 2b).	$50-65 million
d. Support research on underrepresentation in K-12 science education and ways to combat it; promote exploratory development of materials and methods especially designed to serve these groups better (Opportunity 3).	$12-18 million
Investments aimed at strengthening professional resources	
a. Fund the development of a teacher support cadre, as in preceding strategy, although less extensively (Opportunity 4).	$60-70 million

* To some extent, reconceptualization of K-12 mathematics content and approaches will happen as part of rethinking science content and approach in Opportunities 2a and 2b.

Table A-2 (Continued)

Area of Opportunity/Initiatives	Estimated Resources (Over 5 years)
Investments aimed at strengthening professional resources (continued)	
b. Expand and experiment with incentives for attracting new teachers, especially those with strong scientific backgrounds; further the investigation of teachers' pedagogical knowledge; fund extensive experiments with trouble spots in the teacher preparation process and alternative ways to prepare teachers; support leadership development among science and mathematics teacher educators (Opportunity 5).	$72-92 million
c. Fund leadership development among informal science educators; study the informal science education field and fund research on, and evaluation of, informal science education efforts of various kinds (Opportunity 6).	$27-30 million
Investments aimed at systems upgrading	
a. Form consortium to explore alternative publication routes; support R&D on the "textbook of the future" (Opportunity 7).	$33-45 million
b. Support national dialogue on science testing policy; fund R&D leading to prototypes that test or assess science skills and knowledge more effectively (Opportunity 8).	$12-18 million
c. Fund cross-state research on effects of state reforms (Opportunity 9).	$5-7 million
d. Fund experimentation with new forms of informal science education and ways to link informal science education more effectively with the schools (Opportunity 10).	$42-55 million

Table A-2 (Concluded)

Area of Opportunity/Initiatives	Estimated Resources (Over 5 years)
Related core function investments	
a. Professional interchange: Create collaborative arenas (science education centers or the equivalent; collaborative arrangements in institutions of higher education) in which educators, scientists, and others pursue work related to science education improvement goals; increase incentives for participation of scientists and engineers in science education improvement; support network development, especially among groups not currently in the mainstream of science education; create an NSF-based journal for the science education community (parallel to *Mosaic*).	$62-80 million
b. Knowledge-building: Fund extensive research on learning and learning environments, both to extend basic understanding and to complement content reexamination; pursue heavy exploratory investment in advanced educational technologies; support monitoring and analyses of the science education system emphasizing projected future conditions; fund evaluative research, concentrating on sets of projects that experiment most with content and approach.	$75-97 million
c. Support for innovative ideas, unanticipated opportunities (as part of each K-12 science education program).	$42-50 million
TOTAL:	$580-739 million

Appendix B

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This study represents the joint efforts of a large and diverse professional team, supplemented by the ideas and advice of many resource people from the science education community. We wish to acknowledge their many contributions to the project and to this report and thank them for their patience and flexibility as the study unfolded.

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